AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS FOR THE NSTS

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ANNUAL REPORT

BY

JOHN L. HUNSUCKER

AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS FOR THE NSTS AT NASA

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ANNUAL REPORT (JAN. 15, 1988 - JAN. 15, 1989)

BY

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EXECUTIVE SUMMARY
AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS
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This report is divided into 8 chapters with 22 appendices and represents the annual report summarizing the research and work effort carried out in 1988 by a team from the Department of Industrial Engineering, University of Houston. The work on which this report is based is a continuation of the effort started in 1985. While this report stands alone for the most part, the reader should read the work which went before in annual reports for insight into the logic presented. In addition, the reader may prefer to read the expanded summary and appeal to the annual report for specific details since the annual report serves as the resting place for all the work.

Chapter I deals with preliminary considerations and contains an introduction, the description of personnel, a list of definitions, and discussions of the work effort, structure, and overview. The chapter concludes with acknowledgments. **Chapter II**, Expansion and Verification of Knowledge, contains the notes and conclusions of the industrial interview process and the presentation of the publications and presentations that have resulted from the work. **Chapter III**, Management and Structure, deals primarily with management philosophy and an analysis of the agenda of the Deputy Director of the Program Office of NSTS. It includes 8 appendices related to one or the other of these topics. **Chapter IV**, Statistics for Managerial Decision Making, is related to the expansion of the use of statistics in decision making for the shuttle program. This Chapter contains a brief discussion of this, along with examples, and recommends that the short course developed to teach the basics of managerial decision making be continued. **Chapter V**, The Management of Change, covers theoretical and training concepts dealing with the management of change. **Chapter VI**, An Analysis of Space Shuttle Scheduling and Flight Rate Problems, deals with two analytical problems, scheduling and the determination of the possible flight rate. **Chapter VII**, Demographic Modeling of JSC, presents a demographic model of the professional employees at JSC for 1988 and a comparison of the years 1984 through 1988. **Chapter VIII**, Recommendations and Conclusions, contains assumptions, goals, and recommendations for NASA and NSTS. The 6 major recommendations are: 1. Educate NASA on the differences between R/D and operations, 2. Design for production and quality, 3. Determine the strategic and tactical goals and objectives for NSTS, 4. Devise a plan to provide for new skills and leadership in the organization, 5. Evaluate and initiate operational strategies, and 6. Initiate research into space

operations engineering. There are 4 research goals presented: 1. The theory of transition management needs to continue to be enlarged, refined, and adapted for the shuttle program needs, 2. Analytical tools of use to the shuttle program need to continue to be developed and presented, 3. Operational issues and industrial engineering tools need to continue to receive exposure, and 4. The research team needs to find a way to receive exposure in the methods which are used by other nations to process space flights.

Accompanying this report, in a second volume, is an expanded summary which includes the concepts presented in a more compact form and excludes the appendices.

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I. PRELIMINARY CONSIDERATIONS

1.0 INTRODUCTION

This document, Investigation of Transitional Management Problems for the NSTS at NASA, is a final report summarizing the research carried out in 1988 under a one year contract between the National Space Transportation System (NSTS) and the Department of Industrial Engineering at the University of Houston, Houston, Texas. The main purpose of this research is to provide analysis and recommendations to the NSTS on managing the transition from a research and development (R/D) structure to an operational structure. This contract represents a continuation of work originally begun in 1985 and seeks to add depth and application to the previous work.

2.0 PERSONNEL

One professor and three graduate students performed the research for this grant. The principal investigator was Dr. John L. Hunsucker, Associate Professor of Industrial Engineering and Assistant Dean of the College of Engineering at the University of Houston. In addition, Dr. Hunsucker also serves as the Director of the Engineering Management Graduate Program. Two graduate students, Mr. Shaukat Brah and Mr. Randal Sitton, have been involved with this project from its inception. A third graduate student, Mr. David

Loos, who started working last year had to leave in the early stages of the project because of his other commitments. Subsequently, Mr. Daryl Santos was brought into the project as a third graduate researcher.

3.0 DEFINITIONS

- Operations or Operational Era - At NASA, the term "operations" is normally used in a somewhat different sense than in this report. NASA has considered the shuttle program to be operational once it completed its four scheduled test flights. However, when we refer to operations here, we mean an organizational structure set up to insure routine, timely performance. In the sense it is used here, operations is synonymous with production.
- Research and Development (R/D) - The term R/D includes research, development, design, testing, and evaluation (DDTE). It is also synonymous with the term "design".
- Strategic Planning - Long-term planning.
- Tactical Planning - Short-term planning.
- Goal - A desired future state, oftentimes stated in philosophical terms.
- Objective - A specific action whose accomplishment will help obtain a goal. Objectives are usually quantifiable.
- Flight Rate - The number of flights per year.

4.0 WORK EFFORT

The work effort for this project consisted of seven parts:

1. A literature search and analysis with emphasis on the transition management and some of the essential tools for the smooth operational management.
2. Based on literature searches, the analysis and results of the questionnaire circulated last year, and interviews, identification of techniques which are applicable to the transition of NSTS and presentation of them to management.
3. The development of scheduling methodologies for designing operational tools for the steady performance of the space shuttle program. The work also includes developing of the prediction model for the flight rate of the shuttle.
4. The development of familiarity of integrating statistics in managerial decision making process.
5. The study of the demographic state of the NSTS.
6. Adaptation of all of the results to the NSTS program.
7. Interaction of the research team with NASA management to advise them on transition management.

While much of the first five results are theoretical, the last two involved the day-to-day interaction of the principal investigator with various levels of NASA

management.

5.0 STRUCTURE

This report is comprised of eight chapters, each of which can stand alone with the exception of the last chapter which relies on the previous chapters to support its recommendations and conclusions. Chapter II contains the findings of the industrial interviews. It also contains a list of publication and presentation of the research. This step is essential to verify research and to obtain additional valid comments. Chapter III is devoted to the management issues and contains analysis of management and structure of NSTS program. Several topics such as time allocation and analysis of the deputy director and alternate management styles are covered in this chapter. Chapter IV presents a review of statistical decision making tools for management. It also contains an appendix on the launch prediction for STS-26. Chapter V summarizes different aspects for managing a complex change from an R/D to Operations environment. Chapter VI provides an analysis of the space shuttle scheduling and flight rate problems. Chapter VII takes another look at the demographics of JSC and presents valid concerns. Finally, Chapter VIII contains assumptions, goals, conclusions and recommendations of this study.

6.0 OVERVIEW

Parts of this report, are of course, theoretical in nature. However, in order to fully appreciate the magnitude of the task at hand and methodology of problem resolution, an understanding of the theory is important. An in-depth reading of the complete report is therefore advised.

The intent of this report is to continue to stimulate the problem solving environment at NASA. The change from an R/D to an operational era will only be effective if implemented by NASA itself and not be an outside source.

7.0 ACKNOWLEDGMENTS

The principal investigator would like to express his sincere appreciation for the diligence of the University of Houston research team, without whose efforts this work would not have been accomplished. In addition, thanks are also due to the Management Integration Office of the NSTS at JSC, which not only provided the funding for this study, but whose involvement and support made possible most of the valuable ideas contained in this report.

CHAPTER II

EXPANSION AND VERIFICATION OF KNOWLEDGE

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2.0 VERIFICATION OF KNOWLEDGE

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II B : PRESENTATIONS AND PUBLICATIONS

II. EXPANSION AND VERIFICATION OF KNOWLEDGE

1.0 EXPANSION OF KNOWLEDGE THROUGH INDUSTRIAL VISITATION

The expansion of transition management knowledge was accomplished through an on-going industrial visitation process that has been continued from previous years of research. The purpose of these interviews was to talk with engineering managers of high-technology companies that have similarities with NASA and the NSTS program and document the lessons learned by the interviewees through their involvement in the transition process. During the previous year, interviews with managers at Houston Lighting and Power's (HL&P) South Texas Nuclear Project (STNP) were conducted to gain their insight into the transition of a nuclear power plant from an R&D / construction to an operational mode.

There are many similarities between the shuttle program and the building of a nuclear power plant. The plants are highly complex, costly, publicly visible, and represent fairly new technology. There are also some major differences. One is that the NRC applies very stiff controls on the plants and this predicates much of the safety / documentation / production system. Another difference is that there are more than three power plants in existence, unlike the shuttle, and there is a large collective data base that is used to support design and operation.

The STNP interviews revealed numerous valuable concepts

and insights into the transition of high-technology projects. The major points are presented in this chapter; the complete field notes from the interviews are contained in Appendix II A. One of the major points of the interviews was that a very complex documentation and document control system is required for the plant to go operational. This system included design morphology of the construction and design of the plant. When one considers that this plant is going to be handed over from the design company to the operational company, the reasons for the completeness and complexity of this system become evident.

Another major point is that they use extensive top-down communication. This has helped them to build, what they think, is a strong team to bring the plant on line. Also, if NASA decides to cross train any of this staff in production techniques, the nuclear industry would be a good candidate for the temporary assignment of staff.

In addition, HL&P found that a necessary step in going to operations is to define an operations culture. One way to define the operations culture is to prioritize the various operational goals. For example, the STNP project has put saftey as the primary goal, followed by reliability of product, people management, cost effectiveness, and public / community interfaces. The interviews also reinforced the concept that operations culture is vastly different than R&D culture.

2.0 VERIFICATION OF KNOWLEDGE

Part of the process of acquiring and verifying knowledge involves sharing ideas and concepts with fellow researchers and practitioners. There are numerous highly qualified researchers in academia and industry, and the intellectual input of such colleagues is very important for the growth and development of the research activity. Therefore, it is very important that the researchers exchange their work in order to simplify and substantiate their research efforts.

Conferences are one of the principal meeting places for the exchange of ideas and thoughts by researchers. During the past year, several papers have been presented at various conferences in order to publicize the research work done on this grant and gain valuable response from different areas of the academic and professional communities. Another channel of verification of theoretical and practical concepts is by means of publication in reputable journals. This mode of presentation usually covers a wider segment of researchers and professionals involved in similar activities. Moreover, most prestigious journals have an elaborate process whereby the submitted paper is scrutinized by several prominent people (known as referees) before it is cleared for publication. Such extensive exploration by the referees improves the quality of the paper, and usually provides good direction for future research. A summary of the presentations and publications of the research is contained

in Appendix II B.

3.0 RECOMMENDATIONS AND CONCLUSIONS

The expansion and verification of transition management knowledge is an important part of this research effort. Through the industrial interview process, first-hand experience into transition management can be acquired, analyzed, and adapted to assist NASA and NSTS make the transition from R&D to operations. It is recommended that additional interviews in subsequent research years be conducted in order to expand the body of transition management knowledge. Also, it is recommended that the knowledge gained through the various research efforts of this grant continue to the presented at various regional and national conferences, and published in refereed publications dealing with engineering management and high-technology.

APPENDIX II A

INDUSTRIAL INTERVIEW FIELD NOTES

FIELD NOTES
INTERVIEW WITH HL/P
SOUTH TEXAS NUCLEAR PROJECT (STNP)
ON 24 MAY 88
JLH-25 MAY 88

1. Attending from the NASA team were George Studor from the Program office, Randall Sitton, a research associate from the University of Houston, and John Hunsucker from the University of Houston.
2. Attending from the company were Jim Westermeier, general manager of the project from HL/P and Ken Hess, the project manager for Bechtel.
3. HL/P is serving as the overall project manager for themselves and three other owners: Central Power and Light, the City of San Antonio, and the City of Austin. There was some indication that Austin is going back out of the project.
4. JW works for the nuclear Group VP, Jerry Goldberg and reports to him. (See the org chart for more information.)
5. HL/P's role is to monitor the performance of the contractors and to direct and correct as required.
6. Bechtel reports to JW. They are the A/E firm and the engineer of record for the project. Bechtel assumed this role from Brown/Root. Bechtel is also the construction manager. (See the org chart for more information.) Ebasco is serving as the constructor.
7. JW stays current on engineering and makes the final decision changes on configuration changes. The Design engineer can make interim changes subject to the subsequent formal approval of the JW.
8. STNP has two units. Unit one is now on-line and HL/P is now the engineer of record on Unit one.
9. In their risk analysis they have 29 volumes. They refer to their document as a living document.
10. They use quantitative methods in their hazard analysis.
11. In statistical decision making, they use their own judgement and a staff statistician. In addition, they force presentors to reduce presentations to understandable terms.
12. Their primary hazard analysis system is that required by the Nuclear Regulatory Commission (NRC). To this they have overlaid a significant amount of their own systems.
13. One of their primary documents in hazard control is a Non Conformance Report (NCR). This can be filed by anyone at any level.
14. In general, a contractor fills out an NCR. This must be validated within 24 hours by both Q/A and safety. It is reviewed for safety implications for this plant and for other plants and entered into the national data base if necessary.
15. Typically, an NCR comes from the engineering department or maintenance and goes to the design engineer. It is very rare to have one go from the engineering department to the plant manager to the VP of ops to the GM down to the design engineer.
16. They have around 200 people on site to deal with NCRs.

17. I first described in rough terms the seal problem with Challenger and the meeting at Thiokol. Then I asked why something similar could not happen to them. Both KH and JW were adamant about the fact that an NCR would have been filed and that equipment is not operated when an NCR is filed against it. KW went on to describe a dry firing on Unit one. They activated Unit one with no fuel present and pressurized all lines and boilers. They brought the operating temperature up to operational level. At some point during this process, the contractor discovered that some of the material was substandard. An NCR was filed and KH gave his troops two hours to discover answers before he called off the firing. He also called JW immediately.
18. A non-conforming component can not be used-this is inviolate.
19. Q/A or engineering management can stop work.
20. To be effective, an NCR program must have both a lot of teeth and a lot of discipline.
21. In addition, for the NCR program to be effective, you must stand behind your managers.
22. Almost out of the blue, but perhaps based on comments made in the interview but more likely based on outside information, JW commented that the shuttle program needed to be pulled together stronger.
23. The responsibility to be the engineer of record will pass from Bechtel to HL/P. Then HL/P must decide whether they wish to do it or contract this activity out.
24. In order to pass the responsibility of being the engineer of record from Bechtel to HL/P on Unit one they had a formal decision process consisting of a series of reviews. They started with the design process to insure that design/decision considerations were not lost. Everything was taken back to basic assumptions, documented, and cross referenced. This document is a living document. As changes to design are made, the change and the rationale for the change are included in the document.
25. They refer to this process as the "Modification Program". Emphasized again that all rationale is included in the package.
26. In the modification program there is no substitute for discipline and detail.
27. One of the major attributes of the STNP project is a far reaching, complex document control process. This cost a lot up front but has paid for itself many times over.
28. The documentation system is one of the hardest but most important steps in going operational.
29. (My thoughts---One reason they have to have such a tightly controlled system on documentation is because the responsibility for being the design engineer changes hands. In order to run a plant, you have to know how/why things were done the way they were.)
30. NRC tests their documentation program by sending them the names/descriptions of 12 components which are safety related. Two weeks later, NRC then shows up on site and

expects to see the complete documentation on the 12. In addition on the day they arrive they give the plant the names/descriptions of 6 more components and expect to see the documentation within 24 hours.

31. HL/P has a fairly small (200 or so) people on the design side of the house. These will, for the most part, be absorbed into the operating staff once the design process is over.

32. They have intentionally used mostly local people for entry level jobs.

33. They have a fairly strong educational incentive program. They have a training facility already in place. They have a contract with Wharton Jr. College to teach lower level courses at the facility. They have another contract with the University of Maryland to finish of the training with a BS in nuclear science. About 40 employees per year are allowed in the program.

34. They also use salary considerations and employee clubs as incentives. They do not use quality circles.

35. A large number of the Bechtel and Embasco employees are hired away be HL/P.

36. According to JW, the best motivator is good leadership. To emphasize this point KH pointed out that even though JW had both his office and home in Houston, he stayed on site and had an apartment nearby.

37. JW made the additional point that technical areas tend to be over managed and under led. Upper level management must provide clear direction and guidance.

38. When they finally go on line, they will have about 1200 in operations and 300 in support areas.

39. They do not have a formal program for the fast tracking of rising stars. They do have an effective informal program.

40. Comments on going operational:

    1) A major problem is the consistent tendency to under estimate the size and complexity of the problem and to over estimate abilities.

    2) Going operational on Unit one was a major test of their people. This process brought to the surface the real players.

    3) There was a tremendous excitement in going operational and crossing the finish line.

    4) Their stress level is very high but went up as they went operational.

41. There is a major amount of pride involved with the job. You have to get the people both emotionally and personally involved so that they have pride of ownership.

42. They had a real problem at first in overcoming the separate corporate identities of all the corporations involved: HL/P, Bechtel, Ebasco, Westinghouse, etc. They changed this so that people identified with STNP as opposed to their individual corporations. They used a little symbolic reorientation here by changing the logo on the hard hats to reflect STNP. Now all hard hats have this logo and are (I believe) the same color) as opposed to each

corporation having an individual hard hat.

43. At some point previously, they slimmed down the organization and removed many of the marginal performers. This was probably around the time they changed to the STNP identity.

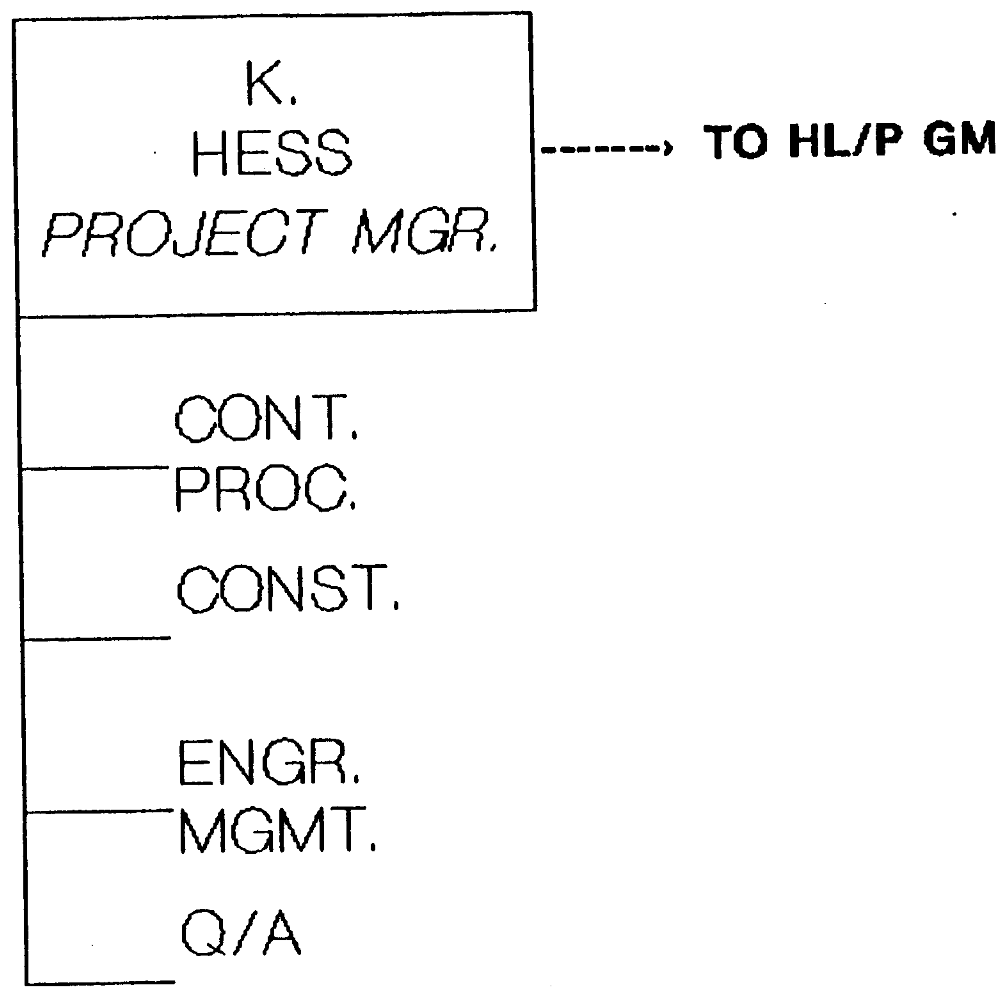
44. Their scheduling is open to everybody and is very public. Major milestones go all the way down to the crafts level. Everyone is aware of these and works towards them.

45. They implied that they use a significant amount of top down communication to keep employees informed and aware. (This is, of course, a significant part of establishing ownership.)

46. They have a very detailed scheduling system and can produce schedules with any level of detail.

47. They have schedule and cost people assigned to each office now. There was an implication that this will continue when they leave construction and go to operations.

BECHTEL



FIELD NOTES
INTERVIEW WITH GERALD D. VAUGHN
VP NUCLEAR OPERATIONS - HL/P
SOUTH TEXAS NUCLEAR PROJECT
ON 5 AUGUST 88
JLH 9 AUGUST 88

1. Attending the meeting were J.L.Hunsucker and R. Sitton from the University of Houston and G. Vaughn from STNP/HLP. Vaughn is an electrical engineer with previous experience in nuclear operations with another power company.
2. STNP currently has one reactor on line and is trying to bring the other one up. They are having some start up problems with the one which is up. The plant is currently undergoing a change from the design/construction phase to the operational one.
3. HL/P has had some significant problems with the STNP and, in addition, has received some bad press because of the plant.
4. In considering design changes, the initial input would probably come from the operational side of the house. Regardless of origin, the first step is to go to ops for a cost justification before going to engineering to determine technical factors of the proposed change. Then the change is sent to a combined committee of ops and design to be decided on.
5. In this change committee, safety is used as a shield to defend the need for a proposed change. The only protection against this shield of safety is a strong comprehensive criterion list which includes other factors and which must be met.
6. A culture needs to be built for the change committee. One important aspect of the culture for going to operations is standardization. If you change one, you should change them all.
7. The very first step in going from design/construction to operations is to decide on priorities. At STNP they are:
a) safety b) reliability of product c) people management d) cost effectiveness e) public/community interfaces.
(See exhibit B of attachment "South Texas Project Electric Generating Station Master Operating Plan included at the back.)
8. Once priorities are established, they must be used by all subgroups in bringing about the change.
9. A necessary step in going to operations is to define an operations culture. The priorities mentioned above are one of the initial steps in establishing this culture. Note that the operations culture is very much different from the R/D construction culture.
10. STNP is heading toward being self sufficient from the contractor/vendor groups.
11. As a part of the culture, the degree of self

sufficiency must be defined.
12. To be cost effective, the degree of sub contract involvement must be reduced.
13. As a control move, contractors are handled by a different group than operations.
14. The intent is to use special contractors for complex tasks but to do day to day work in house.
15. Vaughn has a "plan of the day" meeting for 1/2 hour each morning. In this meeting they discuss the last 24 hours and the next 24 hours. He purposefully does not chair the meeting but attends. He will meet with selected individuals immediately after the meeting to discuss special topics which the meeting touched on.
16. Vaughn seeks out problems by going to meetings such as the one above and by going out into the plant.
17. As part of the culture, he has informed managers, either in writing or orally, what he wants to be kept informed of and what types of items he should be immediately notified of.
18. After I described the seal problem with the shuttle to him, he said he felt that this type of problem would probably not be stopped at STNP and probably would not be stopped with the shuttle. The reason for this is that sub managers have to be given some autonomy in decision making on complex projects. Top management cannot decide everything.
19. They have a program called the Safe Team Group. This is an independent high level review which anyone can access. It is designed particularly for those concerns on which an employee cannot get managerial attention.
20. He personally meets with each new employee, usually in a group format, and covers: a) the Safe Team Group b) standards and long term objectives c) strategies to be used d) management priorities e) professionalism.
21. Some of his employees, at all levels, have moved from the R/D-constructor side of the house to the operational side.
22. They have made safety an important part of the operational culture.
23. It takes an individual with a technical background to do his job. He estimates that some 40% of his job is technical.
24. He spends a goodly amount of time on setting objectives and standards and on deciding where the plant should go. Even this requires a technical background.
25. He estimates that 25-30% of his job is looking forward, 40-45% is today oriented, and 25% is looking backward.
26. He spends a goodly amount of time setting 5 year plans.
27. He has just finished the process of developing a master operating plan (see attachment). A plan of this type, in some form, has to be developed and well defined in order to go operational. While he used subordinates to help with the plan he did the major work.
28. Every goal in the plan has a goal champion who is a key manager but not on the executive committee.
29. They have a succession planning program with a developmental aspect.

30. In the succession plan, they take the top jobs and list the characteristics. These then are priortised for necessity to do the job. Then two or three candidates are identified for each position and assessed. A developmental plan is then devised for each candidate. This developmental plan is very broad based and includes cross training, sometimes outside the company.

31. HL/P takes an aggressive posture in public relations. They take the offensive whenever possible. One of their goals in the public relations program is to insure that their integrity is beyond reproach.

32. In their transition management, they used a blend of the hand over team and the parallel track team approaches.

33. As operations grows, research shrinks, even in the budget. This is very hard for the design group to accept.

34. As an aside, since May, the word "nuclear" has been removed from all references to the plant. The project is now called the "South Texas Project". The plant is now called the "South Texas Project Electric Generating Station". This action extends to the signs around the plant and to the visitor center.

ATTACHMENTS:

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION MASTER OPERATING PLAN

ORGANIZATION CHARTS: NUCLEAR GROUP ORGANIZATION
NUCLEAR PLANT OPERATIONS DEPARTMENT

INTERDEPARTMENTAL PROCEDURES STATION PROBLEM REPORTING

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

MASTER OPERATING PLAN

DESCRIPTION

The Master Operating Plan for the South Texas Project Electric Generating Station integrates the efforts of all nuclear departments in the achievement of operating objectives and goals.

The Master Operating Plan is a rolling, five-year plan providing detailed information for the current and next year and general information for other years. In the process of developing the Plan, the following will be accomplished:

- o Establishment of annual goals which support the Corporate goals and ensure the long term safety, reliability and efficiency of STPEGS;
- o Identification of major work activities required to accomplish the annual goals, and the milestone actions associated with these activities;
- o Development of an integrated schedule for major activities; and
- o Establishment of the work scope to be included in budgets.

The Master Operating Plan integrates the activities of all departments which directly support the South Texas Project Electric Generating Station.

An Executive Committee, with representation from selected groups, is responsible for generating the Master Operating Plan. Direct responsibility for providing input recommendations, monitoring and reporting progress, and coordination of improvement activities will be delegated to specific managers accountable for the respective areas.

STPEGS Performance Indicators will be utilized to track monthly progress for selected goals.

CONTENTS

The Master Operating Plan will be contained in a workbook composed of the following sections:

Section I: Introduction - this contains an overall explanation of the Master Operating Plan, including contents, responsibilities, and administration.

Section II: Objectives and Strategies - this includes a copy of the following documents:

- o Corporate Objectives and Strategies
- o Nuclear Mission Statement (to be developed)
- o STPEGS Long Term Objectives
- o Nuclear Management Priorities

Section III - Goals - this contains the goals which direct the activities of the South Texas Project Electric Generating Station:

A. Corporate Goals - these top down goals set priorities for the overall company and establish standards of performance for the coming year. STPEGS Goals will be established to support the Corporate Goals.

B. STPEGS Goals - these are set each year to ensure continuously improving performance to reach the level of excellence identified in the long term objectives. There are two categories of STPEGS goals:

1. Standing Goals - the Master Operating Plan establishes the following standing goals for STPEGS. Each year the target levels may change, but the goal statements will remain the same.

a. Quality of Nuclear Operations - taken collectively, the following industry "Overall Performance Indicators" (INPO) are indicative of the quality of operations of a nuclear station:

- o Equivalent Availability Factor
- o Unplanned Automatic SCRAMS While Critical
- o Unplanned Safety System Actuations
- o Forced Outage Rate
- o Thermal Performance
- o Fuel Reliability
- o Collective Radiation Exposure
- o Volume of Low-Level Solid Radioactive Waste
- o Industrial Safety Lost Time Accident Rate
- o Safety System Performance

Performance targets will be established for each of these indicators to ensure STPEGS achieves a quality of nuclear operations above industry "median" values. Each indicator will have five year targets established on one sheet with the next year's target prominently displayed.

b. Regulatory Compliance - these goals help STPEGS achieve a high level of compliance to regulatory requirements. Five year performance goals will be established for each of the following:

- o NRC SALP Rating - goals will be set to progressively improve the SALP rating for STPEGS until the long term objective to have the best rating in Region IV is achieved.

- <u>NRC Violation Index</u> - this goal will establish an annual limit for the number of points per NRC inspection. Points will be awarded according to the following schedule:

  Level III with Civil Penalty = 50 pts
  Level III without Civil Penalty = 30 pts
  Level IV Violation = 20 pts
  Level V Violation = 10 pts
  No Level I or II Violations

- <u>Environmental Exceedances</u> - this goal sets progressively lower target levels for the number of Exceedances of STPEGS environmental permits, until the long term objective to be considered a leader in environmental protection is achieved.

c. <u>Employee Relations</u> - these goals will require implementation of the necessary actions to achieve the STPEGS long term objective to be considered an excellent and safe place to work by employees. Specific goals will be established, and typically would include:

- Educational and Career Development - implementation of accredited training programs, implementation of a Management/Supervisory training program, implementation of a job rotation program, etc.

- Human Resources Management - maintain high employee morale and productivity, control of staffing and overtime, Focus Group participation, etc.

d. <u>Financial Management</u> - the overall purpose of these goals is to minimize costs to the ratepayer and ensure a reasonable return on investment to the company's owners. These include:

- Operations and Maintenance Budget
- Capital Budget
- Nuclear Fuels Budget
- Cost per net kilowatt-hour

2. <u>Other Goals</u> - these generally are not recurrent for more than 1 or 2 years. Input for these goals will come from the "bottom up" through the management chain and be presented early in the goal development cycle to the Executive Committee. Where appropriate, goals will be recommended for inclusion as Corporate level goals for the coming year.

Section IV - <u>Master Schedules</u> - identify major activities and events for management awareness and planning purposes.

(A) Schedules will be provided for the current and next year and will include such items as:

- o refueling outages
- o scheduled equipment outages
- o scheduled audits (i.e., INPO, NRC, ANI, Major NA Audits, etc.)
- o testing milestones for Unit 2
- o major work activities which cross department boundaries may be identified on the schedule if requested by the Executive Committee

(B) A five year generation schedule will be provided, which identifies scheduled refueling and equipment outages and other known items of significant impact.

(C) A one-page listing of those known or anticipated major items which impact the Master Operating Plan for the years beyond the five year period will be maintained as the last part of this segment.

Section V - <u>Budget</u> - this section contains a copy of the following approved budgets for the current year:

- o Operations and Maintenance
- o Capital
- o Nuclear Fuels

Monthly reports of budget performance will be included in this section.

Section VI - <u>Performance Indicators</u> - this section contains the latest monthly issue of the STPEGS Performance Indicators.

RESPONSIBILITIES

I. Executive Committee - has overall responsibility for administration of the Master Operating Plan. Membership is determined by the Nuclear Group Vice President and will consist of selected leaders from the major groups at STPEGS.

Responsibilities include:

- o Establish STPEGS goals on an annual basis for the coming year. This includes setting one-year and five year performance targets for standing goals.
- o Recommend goals for inclusion as Corporate level goals where appropriate.
- o Designate a Goal Champion for each goal.
- o Review and approve Goal Achievement Plans.
- o Review and approve the preliminary budget for STPEGS prior to submission to the Nuclear Group Vice President.
- o Monitor progress toward goal achievement, budget expenditures and schedule performance on a quarterly basis, and identify appropriate recovery actions if required.

II. Goal Champions - each goal will have a champion who will coordinate the efforts toward goal achievement. The champion will be designated by the Executive Committee and will normally be the department level manager of the area most related to the goal.

Responsibilities include:

- o Recommend the performance target for the assigned goal to the Executive Committee each year including projections suggested for the next 4 years.
- o Develop the Goal Achievement Plan. This involves direct interface with supporting departments to identify those activities required to achieve the goal. Milestone dates and budget estimates are obtained through feedback from the assigned department and this data is included in the Plan.
- o Present the Goal Achievement Plan to the Executive Committee for approval each year. This includes explanation of how supporting department level activities combine to ensure the goal is met.

- o Monitor progress toward goal achievement and identify problems to the Executive Committee as they arise. From information provided by supporting Department Managers, provide a status report on the Goal Achievement Plan for the Executive Committee's consideration at each quarterly meeting.

III. <u>Department Managers</u> - implement the supporting activities required to achieve established STPEGS goals. Department Managers are the key to the successful implementation of The Master Operating Plan.

Responsibilities include:

- o Recommend STPEGS goals and proposed Corporate level goals to the Executive Committee based upon input from all levels within the department.
- o Provide input and recommendations to the Goals Champions regarding supporting activities to achieve established goals for the preliminary Goal Achievement Plan.
- o Develop internal action plans to ensure assigned support activities are accomplished and obtain management approval.
- o Provide milestone dates and budget estimates to the Goals champions for inclusion in the final Goal Achievement Plan.
- o Develop Department budgets using approved Goal Achievement Plan budget estimates as an input.
- o Implement necessary actions to achieve successful completion of assigned support activities on time and within budget.
- o Provide Goals Champions with periodic (at least quarterly) updates of the status of assigned support activities.
- o Disseminate information concerning STPEGS goals and assigned department supporting activities to all employees in the department. Provide periodic status reports.

IV. <u>All Employees</u> - the Master operating Plan defines the course and destination for STPEGS. All employees must be familiar with the plan and actively support its successful implementation.

Responsibilities include:

- o Recommend new or revised STPEGS goals to the Executive Committee via the management chain. Recommendations for Corporate level goals should also be identified.
- o Maintain an awareness of goal status.
- o Execute required support activities as established by the Plan.

ADMINISTRATION

The process for establishing STPEGS' goals and implementing the Master Operating Plan is summarized in chronological order below:

January

o Master Operating Plan Quarterly Meeting - the Executive Committee receives an update of goal status, schedule performance, and budget expenditures for the past year.

March

o Input received from lowest levels of the plant organization and relayed through the management chain regarding recommended new goals for the next year. The Executive Committee members bring recommendations to the Committee for consideration.

o Executive Committee considers recommendations and identifies STPEGS goals for the next year and assigns Goal Champions. Where appropriate, goals will be recommended for inclusion as Corporate level goals for the coming year.

April

o Master Operating Plan Quarterly Meeting - the Executive Committee receives an update on goal status, schedule performance, and budget expenditures for the current year, and identifies appropriate recovery actions if required.

o Goal Champions commence development of performance targets and preliminary Goal Achievement Plans. This involves direct interface with affected Department Managers to identify supporting activities required to achieve the goals.

May

o Goal Champions present performance targets and preliminary Goal Achievement Plans to the Committee for approval. These identify Department level supporting activities and assign responsibility.

o Executive Committee - meets with Department Managers and above, as a group, to promulgate the approved goals and preliminary Goal Achievement Plans, provide background for goal selection and performance targets established, and provide clarification as required.

o Department Managers commence development of internal action plans to accomplish the assigned activities, work with the Goal Champion on milestone dates and budget estimates.

June

- Department Managers obtain action plan approval through the management chain and convey final milestone dates and budget estimates to the Goal Champion for inclusion in the final Goal Achievement Plan.

- Goal Champions - send the final Goal Achievement Plan to the Executive Committee for approval when satisfied that department level supporting activities and milestone dates are adequate to achieve the goal. This final Plan also identifies budget estimates for each supporting activity.

- June 30 (latest) - Executive Committee approves the final Goal Achievement Plans, and authorizes the required funding to be included in preliminary budgets. Department level budget preparation commences.

July

- Master Operating Plan Quarterly Meeting - the Executive Committee receives an update on goal status, schedule performance, and budget expenditures for the current year, and identifies appropriate recovery actions if required.

- Department budgets are prepared and presented through the management chain for approval.

August

- The Executive Committee reviews the Master Schedule of activities and next year's preliminary budget.

October

- Master Operating Plan Quarterly Meeting - the Executive Committee receives an update on goal status, schedule performance, and budget expenditures for the current year, and identifies appropriate recovery actions if required.

December

- Master Operating Plan for the next year is distributed to appropriate management.

ATTACHMENT A

Section III. Goals

Goal Champions:

B.1.a Quality of Nuclear Operations

- o Equivalent Availability Factor - M. R. Wisenburg
- o Unplanned Automatic Scrams While Critical - J. W. Loesch
- o Unplanned Safety System Actuations - J. W. Loesch
- o Forced Outage Rate - Maintenance Manager
- o Thermal Performance - J. J. Nesrsta
- o Fuel Reliability - D. J. Denver
- o Collective Radiation Exposure - J. R. Lovell
- o Volume of Low-Level Solid Radioactive Waste - J. R. Lovell
- o Industrial Safety Lost Time Accident Rate - J. W. Odom
- o Safety System Performance - (Later)

B.1.b. Regulatory Compliance:

- o NRC SALP Rating - M. A. McBurnett
- o NRC Violation Index - M. A. McBurnett
- o Environmental Exceedances - J. R. Lovell

B.1.c. Employee Relations: J. W. Odom

B.1.d. Financial Management:

- o Operations and Maintenance Budget - D. O. Wohleber
- o Capital Budget - D. O. Wohleber
- o Nuclear Fuel Budget - R. J. Worden
- o Cost per net Kilowatt-hour - J. M. Price

Section IV Master Schedules

Coordinator - W. L. Mutz

Section V Budget

Coordinator - D. O. Wohleber

Section VI Performance Indicators

Coordinator - W. L. Mutz

MASTER OPERATING PLAN COORDINATOR - J. M. PRICE

ATTACHMENT B

MASTER OPERATING PLAN

GOAL ACHIEVEMENT PLAN

GOAL

GOAL CHAMPION:

TEP #	ACTION STEPS	RESPONSIBLE INDIVIDUAL	TARGET DATE	BUDGET ESTIMATE

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EXHIBIT A

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

LONG TERM OBJECTIVES

1. To achieve **excellent station** rating from INPO.
2. To achieve the best **NRC SALP rating average** in Region IV.
3. To be considered an **excellent** and **safe** place to work by employees.
4. To achieve **below average cost per net kwh** produced when compared to similar nuclear plants.
5. To be considered a **leader in environmental protection.**
6. To be recognized as a **leader in citizenship and service** to the community.

Exhibit B

SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

NUCLEAR OPERATIONS

MANAGEMENT RESPONSIBILITIES

I. **Safety of the Public and Station Employees**

- o Safe Operations
- o Releases to the Environment Well Below Limits
- o Personnel Radiation Exposure ALARA
- o Emergency Preparedness
- o Industrial Safety
- o Security

II. **Reliability of Service**

- o High Availability and Capacity Factors
- o Low Forced Outage Rates
- o Necessary Capacity Additions on Schedule
- o High State of Material Condition

III. **People Management**

- o Open Management Style, Mutual Respect and Trust
- o Employee Training and Career Development
- o Positive Employee Relations
- o Professionalism
- o Teamwork

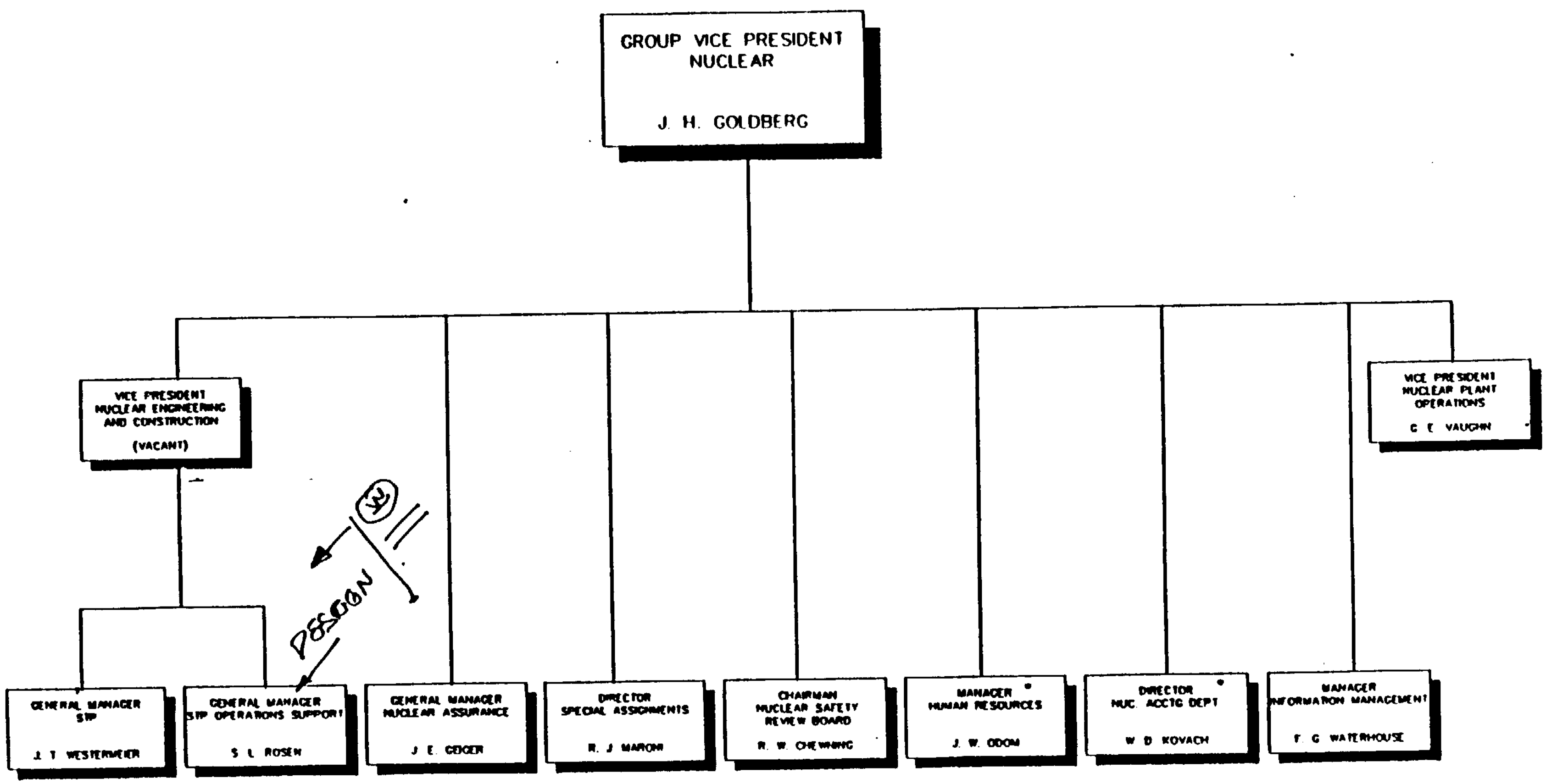
IV. **Efficiency/Cost Effectiveness**

- o Organization
- o Planning and Scheduling
- o Budgets and Cost Control
- o Productivity
- o Heat Rates
- o Cost Per Net KWH

V. **Community and Industry Support**

- o Positive Community Relations
- o Civic and Charitable Activities
- o Industry Group Involvement
- o "Sister" Utility Support

HOUSTON LIGHTING & POWER
NUCLEAR GROUP ORGANIZATION

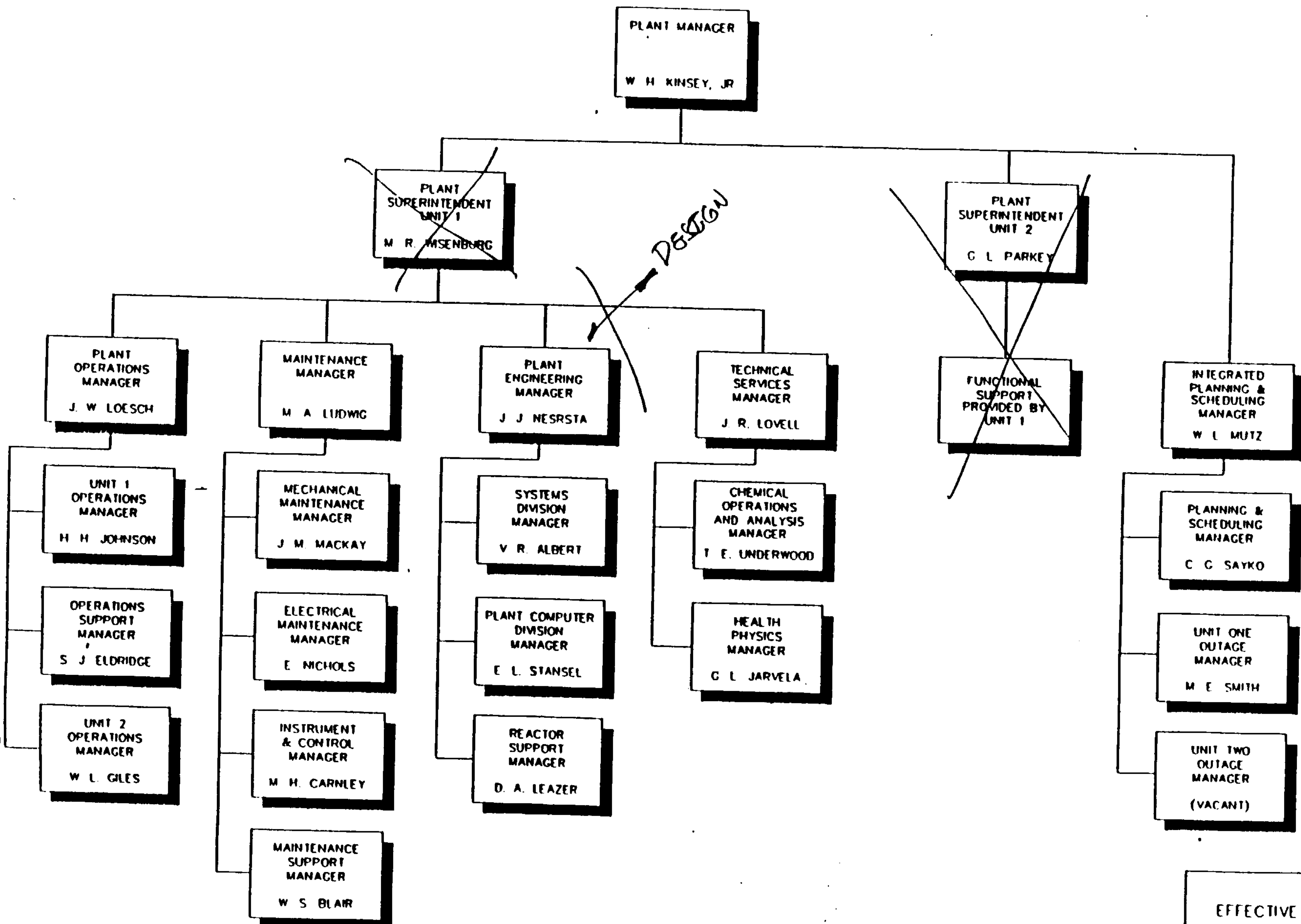


* MATRIXED

EFFECTIVE DATE
APRIL, 1988

HTC-0119

HOUSTON LIGHTING & POWER COMPANY
NUCLEAR PLANT OPERATIONS DEPARTMENT



EFFECTIVE DATE

APRIL, 1988

A SUMMARY OF THE
SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION
INTERDEPARTMENTAL PROCEDURES
STATION PROBLEM REPORTING DOCUMENT

The South Texas Project Electric Generating Station Interdepartmental Procedure is a seventy-two page document that establishes uniform requirements for the management and administrative controls for identifying and correcting conditions that may not conform to established requirements and may impact the safe and reliable operation of the plant. Responsibilities are assigned to identify, initiate, evaluate, analyze, and document the above conditions when discovered by South Texas Project personnel.

The procedure applies to all South Texas Project personnel and all South Texas Project departments for reporting conditions that may not conform to established requirements and may impact the safe and reliable operation of the plant. Any South Texas Project employee may initiate a Problem Report in accordance with this procedure.

The Station Problem Reporting Procedure is intended to document and provide for management review of problems which meet predetermined reporting criteria. Other applicable reporting mechanisms should be used in lieu of this procedure if the predetermined criteria are not met. Also, the Station Problem Reporting Procedure does not replace the Nonconformance Report or Deficiency Report procedures.

APPENDIX II B

PUBLICATIONS AND PRESENTATIONS

APPENDIX II B

PRESENTATIONS AND PUBLICATIONS

PRESENTATIONS

[1] "Analysis of Alternatives for the Management of the Space Shuttle Program". Proceedings of the Eighth Annual Meeting of the American Society for Engineering Management, St. Louis, Missouri, October 11-13, 1987.

[2] "Optimal Scheduling in an m-Stage Flow Shop with Multiple Processors". Presented at the TIMS/ORSA Joint National Meeting, New Orleans, Louisiana, May 4-6, 1987.

[3] "R&D to Operations Transition Management". Presented at the National Decision Science Annual Meeting, Honolulu, Hawaii, November 23-25, 1986.

[4] "Transition Management - A Perspective". Proceedings of the 24th Annual Southern Management Association Meeting, Atlanta, Georgia, November 12-15, 1986.

[5] "Transition Management - A Structured Perspective". Proceedings of the International Conference on Engineering Management: Theory and Application, Swansea, England, September 15-19, 1986.

[6] "Branch and Bound Method for Flow Shop with Multiple Processors Scheduling". Presented at the TIMS/ORSA Joint National Meeting, Washington DC, April 25-27, 1988.

[7] "An Engineering Management Perspective on Transition Management". Proceedings of the Ninth Annual Conference of the American Society for Engineering Management, Knoxville, Tennessee, October, 1988.

PUBLICATIONS

[1] "Disaster on Flight 51-L: An IE Perspective on the Challenger Accident". Industrial Management, Vol. 28, No. 5, 1986.

[2] "An Analysis of the Flight Rate Capability of NASA's Space Shuttle Program". Logistics Spectrum, Journal of the Society of Logistics Engineers, Vol. 21, No. 3, 1987.

[3] "Transition Management - A Structured Perspective". IEEE Transactions on Engineering Management, Vol. 35, No. 3, 1988.

[4] "An Operational Arm for the Management of the Space Shuttle". Submitted to the Annals of Society of Logistics Engineers, 1988.

[5] "Transition Life Cycle - An R&D to Operations Perspective". Submitted to the IEEE Transactions on Engineering Management, 1988.

[6] "Transition Management: An Analysis of Strategic Considerations for Effective Implementation". Submitted to the Engineering Management International, 1987.

[7] "An Engineering Management Viewpoint of Industrial Transition". Submitted to the Long Range Planning, 1988.

[8] "Branch and Bound Algorithm for a Flow Shop with Multiple Processors Scheduling". Submitted to the European Journal of Operational Research, 1988.

[9] "A Survey of Engineering Management Practices in Transition Management". Submitted to the American Society of Civil Engineers' Journal of Management in Engineering, 1988.

[10] "Mobility of Engineers in the Job Market: Frequency and Reasons". Submitted to the International Journal of Manpower, 1988.

[11] "Transition Management: Planning a Complex R&D to Operations Transition". Submitted to Long Range Planning, January 1989.

[12] "Mathematical Modeling of Scheduling Problems". Submitted to the Journal of Operational Research Society, 1988.

WORKING PAPERS

[1] "Optimal Scheduling in a Flow Shop with Multiple Processors". Working Paper, University of Houston, 1988.

[2] "The Problem of Space Shuttle Scheduling". Working Paper, University of Houston, 1988.

[3] "Simulation Study of a Static Flow Shop with Multiple Processors for the Mean Flow Time and the Makespan Criteria". Working Paper, University of Houston, 1988.

[4] "A Study of the Interrelationships of Transition Management Techniques During Organizational Change". Working Paper, University of Houston, 1988.

CHAPTER III

MANAGEMENT AND STRUCTURE

III. MANAGEMENT AND STRUCTURE

1.0 INTRODUCTION

The single most important event of this year has been the resumption of flight with STS-26 and STS-27. The management system is still in a mode of coping with reflight issues and has not as of this time settled into the same routine business as usual format that was prevalent prior to Challenger. It appears that top level management is getting on with the business of flight but still devotes a large amount of time to reflight issues. There are still numerous top level meetings demanding a large amount of executive time. Little, if any, significant change in the process has been made from the process used prior to Challenger. Some titles have been shifted, some work has been reorganized, but the bulk of the main product is still the same. Surely, in a product as complex as space flight, one does not expect to see significant change over a short time period. However, this coming year will demonstrate whether the organization has laid the groundwork to move forward or whether it reverts to the same difficult working environment that existed before Challenger.

What seems to be missing is the "grand vision", the purpose of the program. Where does the shuttle program fit in the overall plan of space exploration and in the goals and needs of the country? Where is the leadership and support

necessary to move the program forward? In blunt terms, if the program has no idea, in the large sense, where it is supposed to be going, how can it hope to get there? Stated another way, how can the program decide if it is doing or has done a good job if there is confusion or ambiguity about what the job is? However, one point is without question. The United States is in real danger of losing its lead in space. This danger will not be mitigated without a well thought out and thoroughly supported space program. At the current time, the shuttle program is the flagship of the space program. To move the country's space program forward, the shuttle program will require the best of strategies and the most substantial support that the country can provide.

2.0 PROGRAM OFFICE DEPUTY DIRECTOR AGENDA ANALYSIS

A significant amount of effort has been devoted this year to doing an agenda analysis of the Deputy Director of the program office. The intent of this analysis is two-fold: to determine how loaded the Deputy Director is as well as how his time is spent and to compare his work effort with a similar analysis done three years ago on the previous head of the shuttle program. The first third of this effort is presented in Appendix III A with a study of the time allocation of the Deputy Director during 1987. This research indicates that the Deputy Director is spending a large amount of time traveling and that this time is forcing a longer work

day. This, in conjunction with the minimal amount of time taken off, forces the conclusion that it will be a rare person indeed who can continue this schedule without suffering from stress and health problems or without having their judgement impaired by the induced fatigue.

The second third of this effort is presented in Appendix III.B as a meeting analysis of the Deputy Director during 1987. This report shows that dealing with HQ takes a significant amount of time and this results in long meetings. Another is that very little future planning is being done. The Deputy Director also spends a large amount of time dealing with technical matters. While this has perhaps been caused by the reflight issues, it does seem large for a top level manager.

The last third of the agenda analysis is presented in Appendix III C, which is a side by side comparison of the agenda analysis of the Deputy Director NSTS Program (1987) to that of the Manager NSTS Program (1984) is presented. This analysis seems to imply that the job is less independent than it once was. In other aspects, such as the temporal concentration on immediate issues, the job is much the same.

3.0 MANAGEMENT PHILOSOPHY

A major effort of this year's research was on helping NASA to find alternative methods of managing work. Appendix III D, A Tentative Outline For Investigation Into Alternative

Management Styles, is a document that begins to define this effort. It defines the basic issues, how NASA is different from other organizations, the types of businesses that NASA needs to examine, and typical questions that need to be asked.

Appendix III E presents a discussion on how variability in shuttle missions must be reduced in order to increase the flight rate. One way to accomplish this is by examining the various payloads with respect to how they affect shuttle processing. Similar payloads could be grouped into "compartments" that could offer price incentives or early launch considerations to shuttle users whose payloads meet certain compartment specifications. Also, a plan is discussed in the appendix for standardization of shuttle flights.

An experiment in the use of statistics to determine the validity of opinion regarding the predicted launch date of STS-26 is presented in Appendix III F. The results of this experiment indicate that the sample chosen was relatively effective in predicting the date of launch.

Appendix III G contains a discussion on the development of a "lessons learned" document based on the experience that the shuttle program management had in recovering from the Challenger accident. A list of questions or subjects is offered which may be valuable in the future for describing how management dealt with the aftermath of the accident.

The last appendix of this chapter, Appendix III H,

presents an overview of Coordination Theory, which attempts to describe how interdependent groups interact. This appendix discusses the various types of interaction patterns, orientations, strategies for managing intergroup performance, and devices for coordination. It also offers a bibliography of books and publications on the subject of Coordination Theory.

APPENDIX III A

1987 NSTS DEPUTY DIRECTOR TIME ALLOCATION

APPENDIX III A

TIME ALLOCATION 1987 DEPUTY DIRECTOR NSTS

JLH FEB 87

1.0 INTRODUCTION

The information in this broadside was compiled from the personal agenda kept by the Deputy Director showing hours worked and days of travel. Several comments are important about the numbers contained herein. If a day was listed as a travel day then the entire day was allocated to the travel category. The work time includes all time which was not under the control of the Deputy Director to do with as he wished. As a specific example of this last comment, a travel day was counted as 24 hours worked. In calculating weekday or week end work hours, only the hours spent on site at JSC were counted.

2.0 DISCUSSION

Table One is a break down of the time by days. In some sense it is a bit misleading since it does not show how much of each day was worked. However, 10.67 hours were averaged per week day and 1.54 hours were averaged for week end day. Another piece of interesting data not contained in the table is that a total of 33 trips were taken accounting for some 93

days.

Table Two shows the allocation of time for the 261 week days in 1987. Table Three shows the minimal expected time assuming an eight hour day, 26 days of annual leave, 10 holidays, and no week end work. Table Three also shows the actual time worked. All of the data in Table Three is in hours. Table Four is compiled from Table Three simply showing the totals of hours worked and hours off.

The Charts One through Four show the same information as the Tables except in graphic form.

3.0 CONCLUSIONS

In order to reach conclusions about the information presented some comparative indices may help. A MYE is defined as 2080 hours and a MSY (Minimal Standard Year) is defined as 1800 hours. Note that an MSY is an MYE with holidays and vacation subtracted. The amount of time that should be allocated to work for a travel day also must be considered. A reasonable assumption is that the work for a travel day is some where between the average time for a weekday, 10.67 hours, and 24 hours. Using these assumptions and definitions and totaling actual time worked on week days and week ends with the approximated time for travel days we get the following approximators for time worked:

$$1.56 \text{ MSY} < \text{TIME WORKED} < 2.25 \text{ MSY}$$

$$1.35 \text{ MYE} < \text{TIME WORKED} < 1.95 \text{ MYE}$$

If the actual hours worked are examined and the travel hours are ignored, then the longer work day, week end work, working on holidays, and not taking annual leave seems to have been used to exceed the minimal expected hours on site. The total actual work hours on site is 1825.2 which exceeds the minimal expected 1800. A tentative conclusion that can be reached is that the large amount of travel is forcing the longer work days.

While no one expects an upper level manager to work only the minimal amount expected, the amount of hours worked in 1987 along with the absence of time off does seem in excess of what is reasonable. It is a rare person indeed who will be able to continue this schedule without suffering from stress and health problems or without having their judgement adversely affected by the induced fatigue.

TIME ALLOCATION 1987
DEPUTY DIRECTOR NSTS

WEEK DAYS WORKED	156
A/L TAKEN	7
TRAVEL DAYS	93
W/END DAYS WORKED	35
W/END DAYS OFF	69
H/D TAKEN	5
TOTAL	365

TABLE 1

TIME ALLOCATION 1987
WEEK DAYS (261 DAYS)
DEPUTY DIRECTOR NSTS

DAYS WORKED	156
A/L TAKEN	7
TRAVEL DAYS	93
H/D TAKEN	5
TOTAL	261

TABLE 2

TIME ALLOCATION 1987
MINIMAL EXPECTED TO ACTUAL
DEPUTY DIRECTOR NSTS

MINIMAL EXPECTED HOURS

WORK HOURS	225×8	1800
OFF A/L HOURS	26×24	624
OFF H/D HOURS	10×24	240
OFF WEEK DAY HRS	225×16	3600
OFF WEEK END HRS	104×24	2496
TOTAL	365×24	8760

ACTUAL HOURS	FORMULA	RESULT
W/D WORK HRS	1664.7	1664.7
TRAVEL HRS	93×24	2232
W/E WORK HRS	160.5	160.5
W/E OFF HRS	104×24	
	-160.5	2335.5
H/D OFF HRS	5×24	120
A/L OFF HRS	7×24	168
W/D OFF HRS	156×24	
	-1664.7	2079.3
	365×24	8760

TABLE 3

TIME ALLOCATION 1987
MINIMAL EXPECTED TO ACTUAL
DEPUTY DIRECTOR NSTS

MINIMAL EXPECTED HOURS

WORK HOURS		1800
OFF HOURS	624	
	240	
	3600	
	2496	6960
TOTAL		8760

ACTUAL

WORK HRS	1664.7	
	2232	
	160.5	4057.2
OFF HOURS		
	2335.5	
	120	
	168	
	2079.3	4702.8
TOTAL		8760

TABLE 4

TIME ALLOCATION 1987
DEPUTY DIRECTOR NSTS

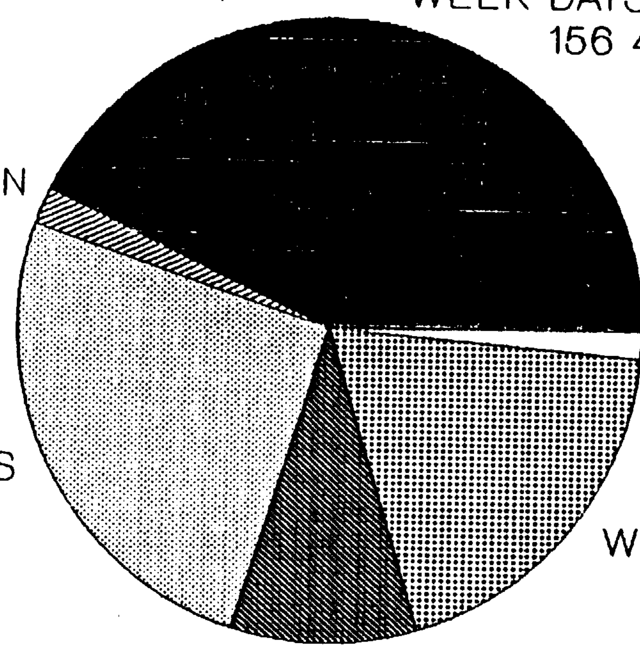


CHART 1

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TIME ALLOCATION 1987
WEEK DAYS (261 DAYS)
DEPUTY DIRECTOR NSTS

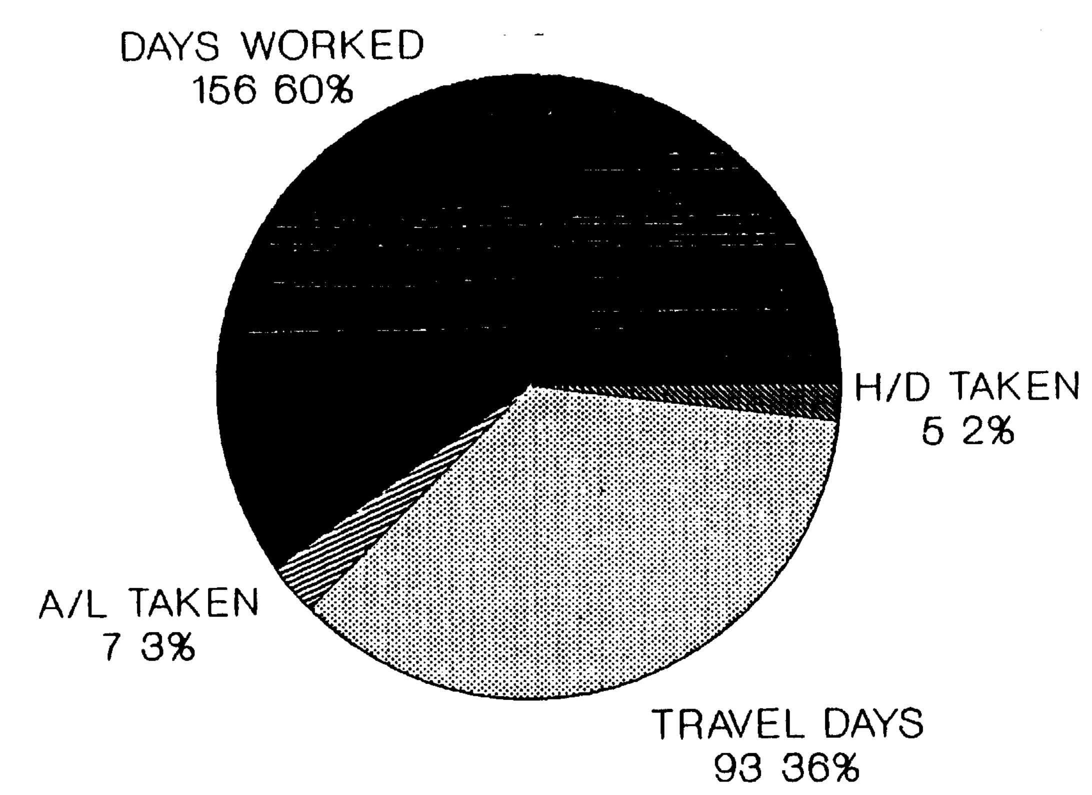
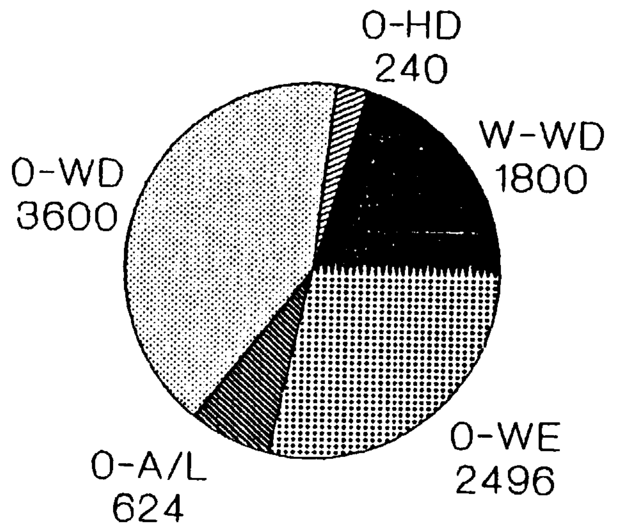
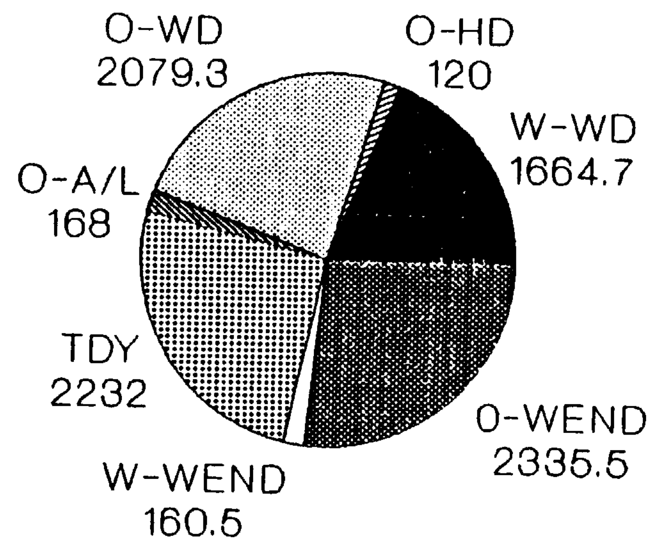


CHART 2

TIME ALLOCATION
MINIMAL EXPECTED TO ACTUAL
DEPUTY DIRECTOR NSTS 1987



MINIMAL EXPECTED
(HOURS)



ACTUAL
(HOURS)

CHART 3

TIME ALLOCATION 1987
MINIMAL EXPECTED TO ACTUAL
DEPUTY DIRECTOR NSTS

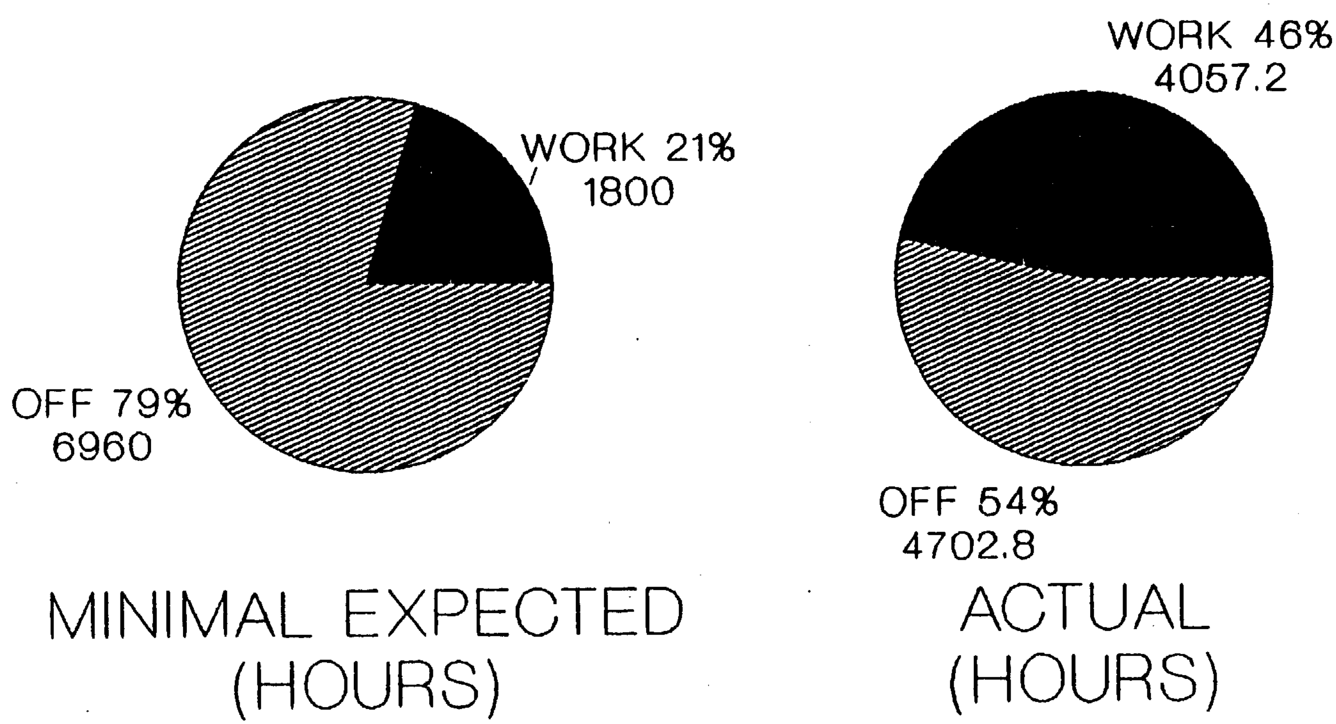


CHART 4

APPENDIX III B

1987 NSTS DEPUTY DIRECTOR MEETING ANALYSIS

MEETING ANALYSIS FOR 1987
DEPUTY DIRECTOR
NSTS PROGRAM
JLH 8 JULY 88

INTRODUCTION: The following charts and information were taken from the 1987 agenda of the Deputy Director of the NSTS Program Office. Each meeting was categorized in four ways: the level of the meeting, the temporal time frame of the meeting, the location of the prime attendant of the meeting other than the Deputy Director, and the subject. The following gives the classifications that were used for each category:

LEVEL	TEMPORAL	LOCATION	SUBJECT
DOWN	NOW	JSC	MANAGEMENT (M)
UP	PAST	NASA OTHER (NO)	TECHNICAL (T)
ACROSS	FUTURE	OTHER (O)	BUDGET (B)
		DOD	PERSONAL (P)
		HQ	

Level refers to whether the meeting dealt with an individual of approximately equal, less, or greater status. The temporal category refers to whether the subject of the meeting was current, from the past, or a future issue. To be classified as future, roughly, a two year time frame was used. The location category is self explanatory. In the subject category, a meeting was a technical meeting if it required technical or engineering expertise on the Deputy Director's part. The personal classification refers to items such as handing out awards, meeting individuals, giving interviews to the press and others. It did not include any personal time such as doctor's appointments or leave.

The results of this analysis are contained in the eight charts and the first of the three tables in the back of this report. The last table contains classifications of various meetings that occurred frequently.

RESULTS: There were 1073 meetings taking a total of 1525 hours for an average of 1.42 hours per meeting.
Level: The majority of the meetings were down both by time and number. While the up and across categories were essentially tied by number, the up meeting took more time and in fact had a greater average time per meeting (3.31 hours per meeting) than any other classification in any category with the exception of the HQ classification for the location category.
Temporal: Almost all meetings were classified as now with virtually none as past and only a few as future. Most of the future meeting were related to the budget.
Location: Most of the meetings were classified as JSC with NO, O, HQ, and DOD following in that order. However, by time, NO led followed by JSC, HQ, O, and DOD in that order.

Note that the HQ classification for this category had the longest average time of all classification of all categories (4.52 hours per meeting).

Subject: The order for both number and time was technical, management, budget, and personal. Roughly half of the time and half of the number of meeting was spent on technical subjects.

The top five meetings:

BY NUMBER					BY TIME				
NUMBER	CLASSIFICATION				TIME	CLASSIFICATION			
246	D	N	JSC	M	449.50	D	N	NO	T
231	D	N	NO	T	200.00	U	N	HQ	M
194	D	N	JSC	T	167.50	D	N	JSC	M
48	A	N	JSC	M	163.75	D	N	JSC	T
44	U	N	JSC	M	125.25	U	N	HQ	T

DISCUSSION: Several issues stand out from the analysis. One is that dealing with HQ takes a lot of time and results in long meetings. Another is that very little future planning is being done. The Deputy Director also spends a large amount of time dealing with technical matters. While this has perhaps been caused by the reflight issues, it does seem large for a top level manager.

An interesting result is that very little time (7.25 hours) is spent on personal matters with JSC staff. One of the results of previous work on operational environments is that a large amount of time is spent by top level management in this area.

LEVEL
NUMBER OF MEETINGS

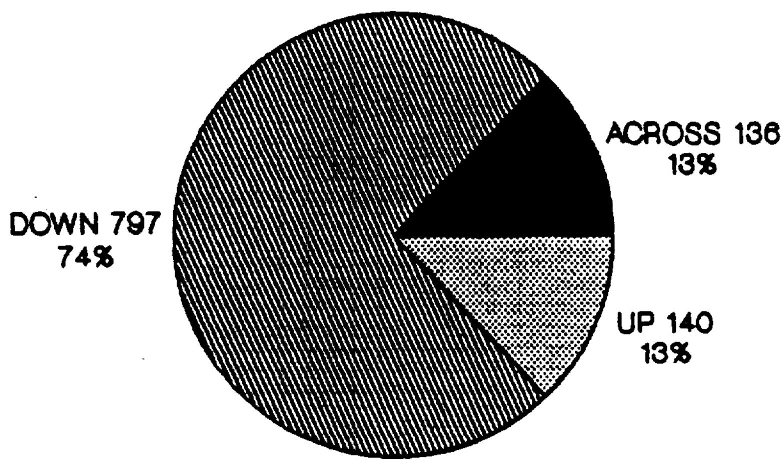


CHART 1

TIME OF MEETINGS

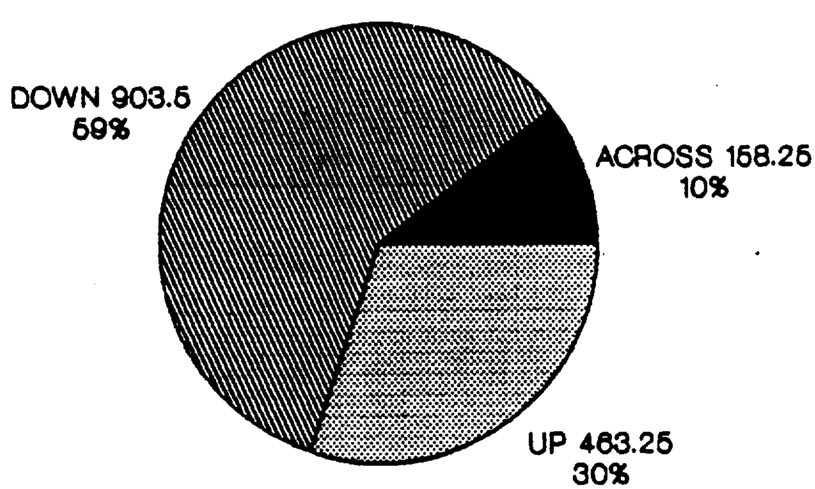
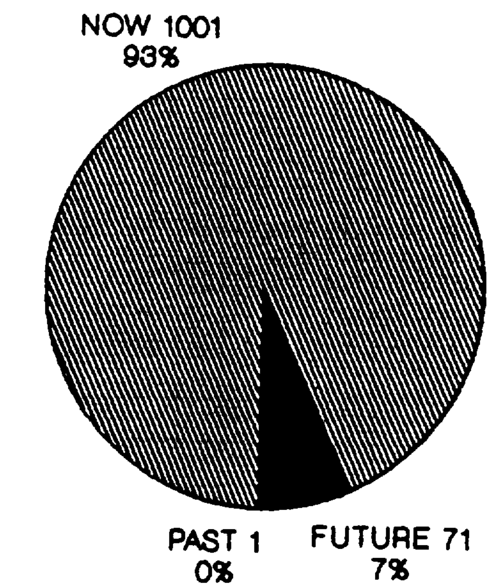


CHART 2

TIME FRAME
NUMBER OF MEETINGS



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TIME OF MEETINGS

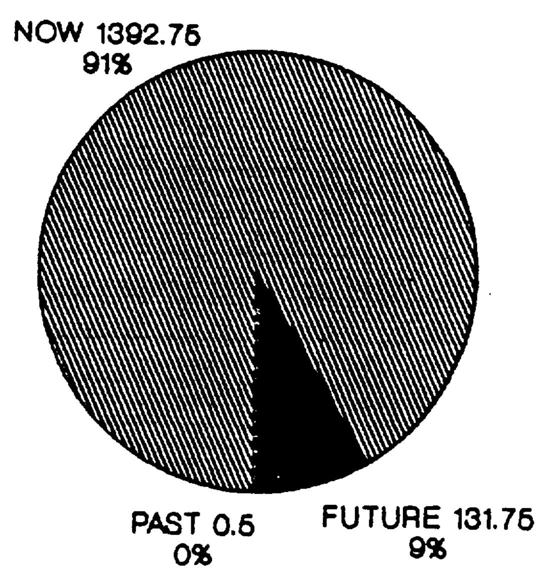


CHART 4

LOCATION
NUMBER OF MEETINGS

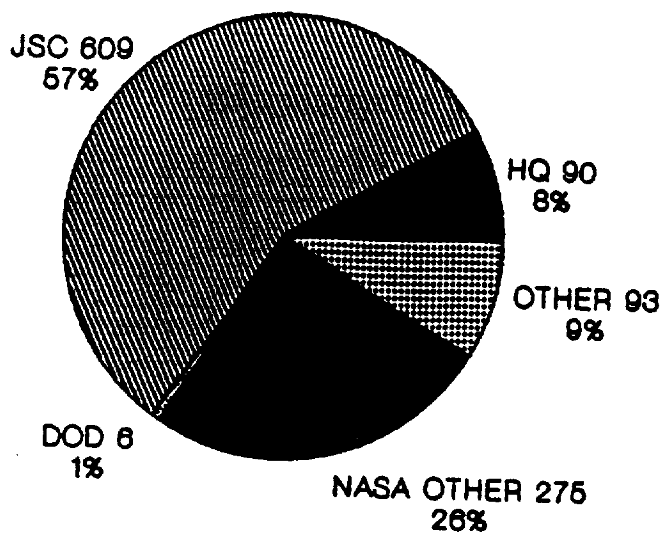


CHART 5

TIME OF MEETINGS

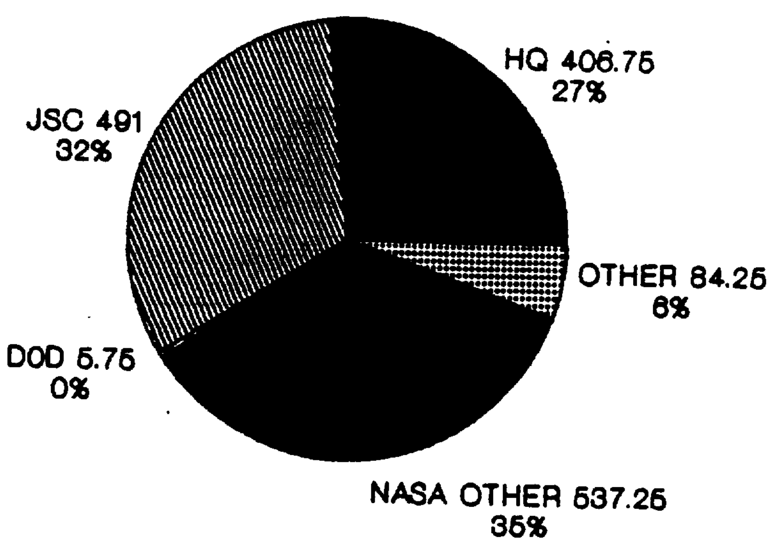


CHART 6

SUBJECT
NUMBER OF MEETINGS

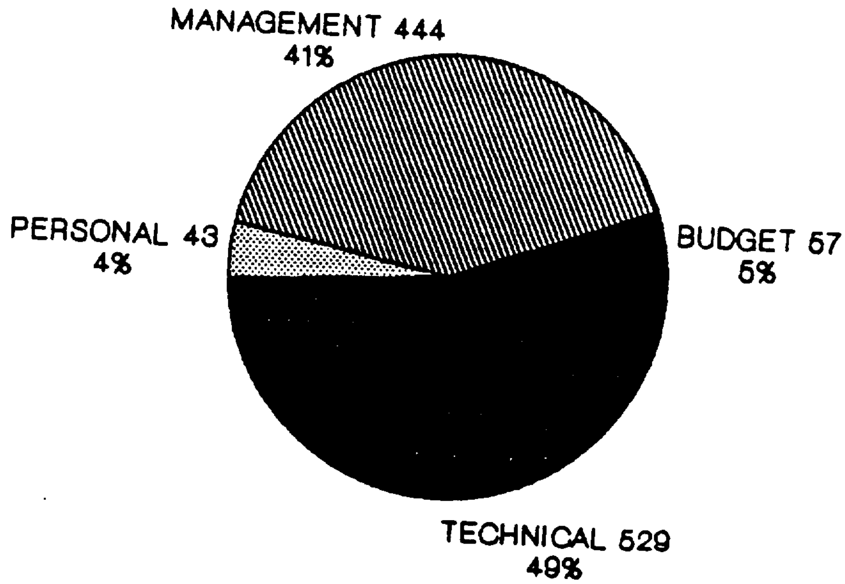


CHART 7

TIME OF MEETINGS

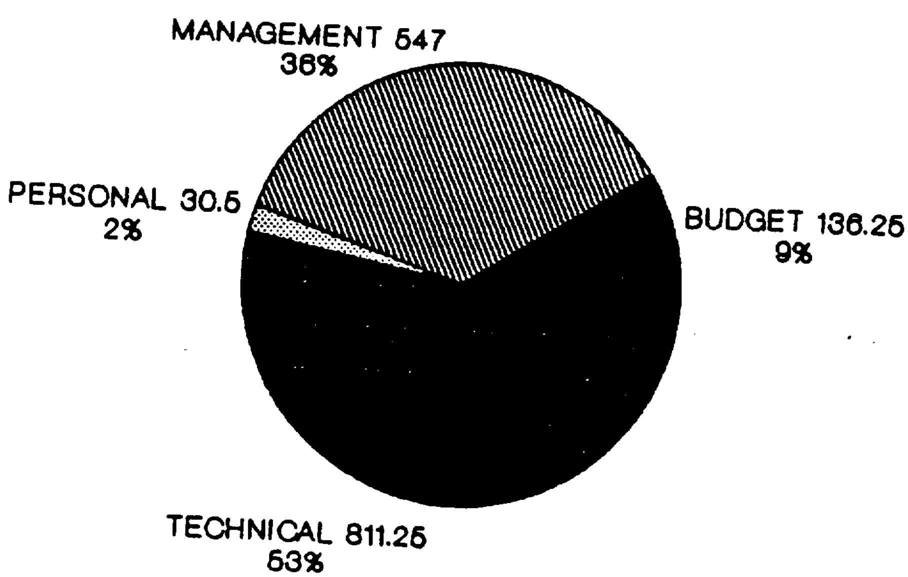


CHART 8

AGENDA SUMMARY CHART
BY MAJOR CATEGORY
1987

NUMBER OF OBSERVATIONS	1073
TOTAL TIME	1525 HOURS
AVG. TIME/OBSERVATION	1.42 HOURS

LEVEL

	NUMBER		TIME		AVG. TIME
ACROSS	136	12.7%	158.25	10.4%	1.16
DOWN	797	74.3%	903.50	59.2%	1.13
UP	140	13.0%	463.25	30.4%	3.31

TIME FRAME

	NUMBER		TIME		AVG. TIME
FUTURE	71	6.6%	131.75	8.6%	1.86
NOW	1001	93.3%	1392.75	91.3%	1.39
PAST	1	0.1%	0.50	0.0%	0.50

LOCATION

	NUMBER		TIME		AVG. TIME
DOD	6	0.6%	5.75	0.4%	0.96
HQ	90	8.4%	406.75	26.7%	4.52
JSC	609	56.8%	491.00	32.2%	0.81
NASA OTH.	275	25.6%	537.25	35.2%	1.95
OTHER	93	8.7%	84.25	5.5%	0.91

SUBJECT

	NUMBER		TIME		AVG. TIME
BUDGET	57	5.3%	136.25	8.9%	2.39
MGMT.	444	41.4%	547.00	35.9%	1.23
PERSONAL	43	4.0%	30.50	2.0%	0.71
TECH.	529	49.3%	811.25	53.2%	1.53

SAMPLE CLASSIFICATIONS AND GROUND RULES

SAMPLE CLASSIFICATIONS:

STANDUP	D	N	JSC	M
GA STAFF	D	N	JSC	M
STATUS TO COHEN	U	N	JSC	M
SR STAFF	A	N	JSC	M
PRCB (I/II)	D	N	NO	T
FRF	D	N	NO	T
SPRCB	D	N	NO	T
PDMR	U	N	HQ	M
SDRB OR SDR	D	N	NO	T
CLRB	U	N	HQ	T
MGT COUNC	U	N	HQ	M
COSTELLO/PROG CONT/ POP	D	F	JSC	B
FMEA/CIL OR CIL	D	N	NO	T
STRAT. PLANNING	?	F	?	M
LEV I PRCB	U	N	HQ	T
CREW ESCAPE	D	N	JSC	T
VLS EQ LOAN	D	N	NO	T
CIR	D	N	O	M
PEB	U	N	JSC	M
LAUNCH SIT FLOW REV	D	N	NO	T
GMSR	U	N	HQ	M
INTERVIEWS	D	N	O	P
MSFC/KSC POP REV	A	N	NO	B

GROUND RULES:

1. Noon board = 0.5 hrs.
2. Standup = 0.5 hrs.
3. Assume Deputy Director chairs both of above unless direct conflict with other meetings or travel.
4. PDMR/Mgmt Council = 8 hours.
5. FMEA/CIL are classified as down since they are a first time presentation to the Deputy Director.
6. Weekend/holiday meetings with start time only listed are classed as time = 1.0 hours.

APPENDIX III C

NSTS DEPUTY DIRECTOR AND MANAGER AGENDA COMPARISON

AGENDA COMPARISON
DEPUTY DIRECTOR NSTS PROGRAM 1987
TO
MANAGER, NSTS PROGRAM 1984

BACKGROUND: In 1985 an agenda analysis was done on the Manager of the NSTS Program Office using his 1984 agenda. Since that time the title of the office has changed to Deputy Director NSTS Program and the management structure has changed somewhat. In 1988 an equivalent analysis was done on the agenda of the Deputy Director NSTS Program using his 1987 agenda. The charts presented at the end contains a side by side comparison of these two tasks. Care should be taken in forming too strong an opinion from this data due to the subjective nature of categorizing the meetings.

RESULTS: RK spends about 20% as much time working across as GL but 170% as much time down and 190% as much time up. Regarding the time frame, the majority of the time, by a significant percent, in both case was spent with current matters with trace elements of the future and almost no time was spent on the past. In the location category, the DOD time essentially disappeared. RK spent more time with HQ and NASA other and less time with JSC and other than did GL. In the subject category, management time was halved and technical time doubled from 1984 to 1987. Budget time grew and personal time shrinked.

COMMENTS: A few very tentative conclusions can be reached from the data. One is that the job now is, to some degree, less independent than it was in the past. A goodly portion of time is currently spent with upper management and less time across. Another conclusion is that the job, in some sense, has become more technically oriented.

In many ways the job is unchanged. The Program Office is still a "now" organization with little time spent on the future and virtually no time spent looking backwards. Budget and personal subjects are still far behind management and technical issues.

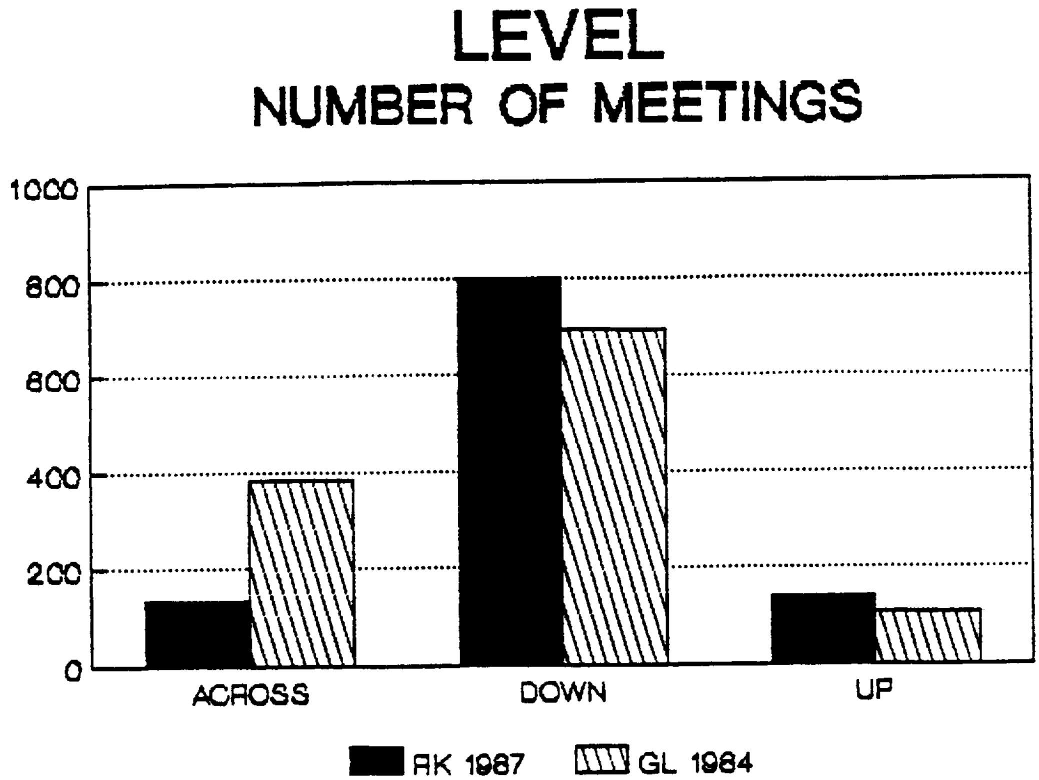


CHART 1

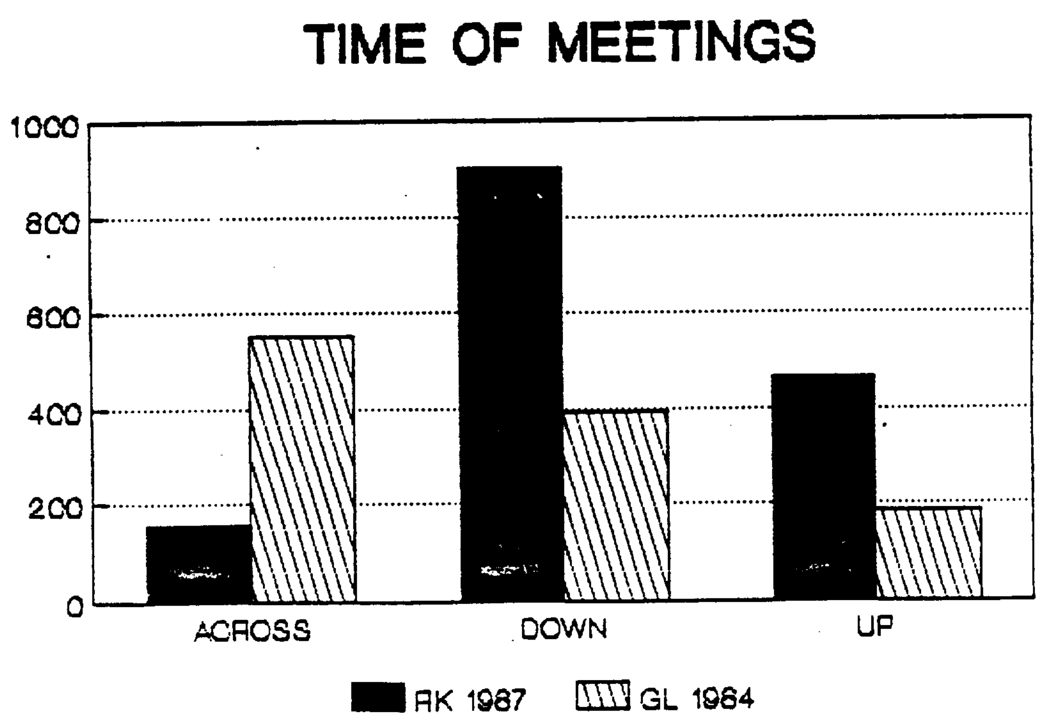


CHART 2

TIME FRAME
NUMBER OF MEETINGS

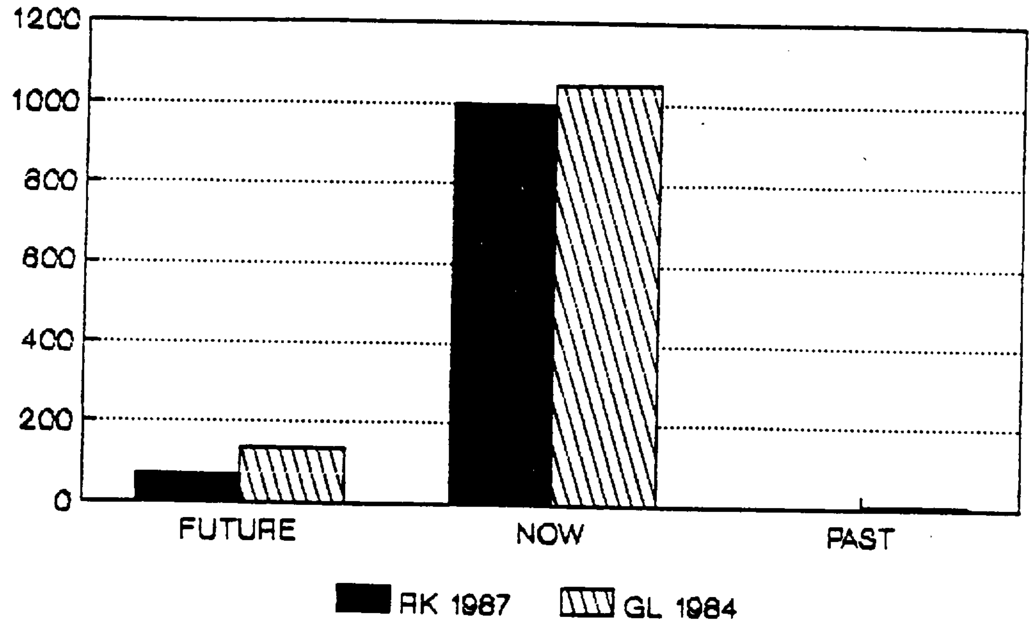


CHART 3

TIME OF MEETINGS

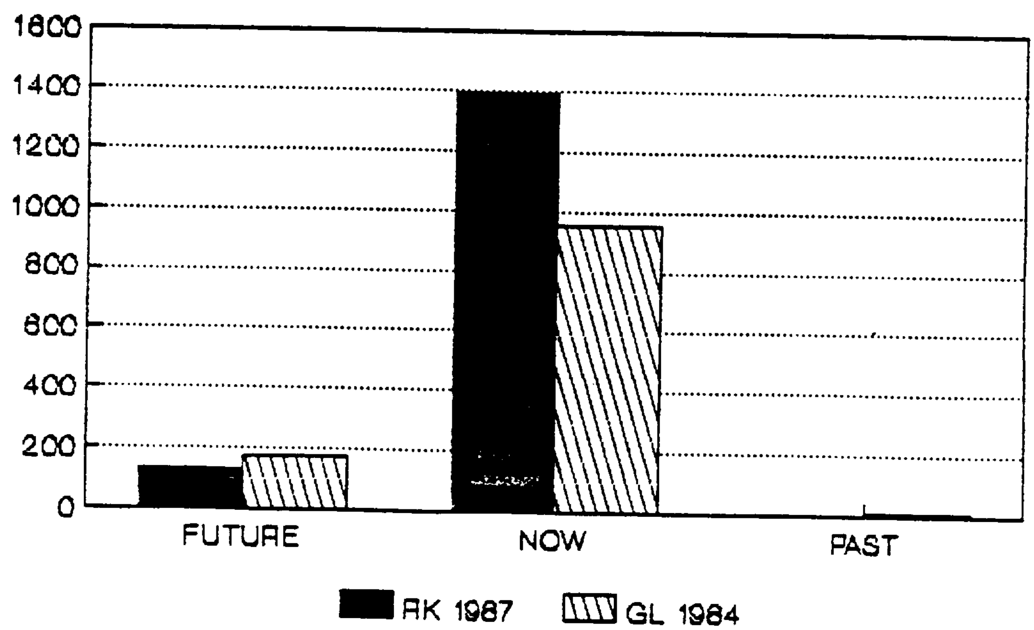


CHART 4

LOCATION
NUMBER OF MEETINGS

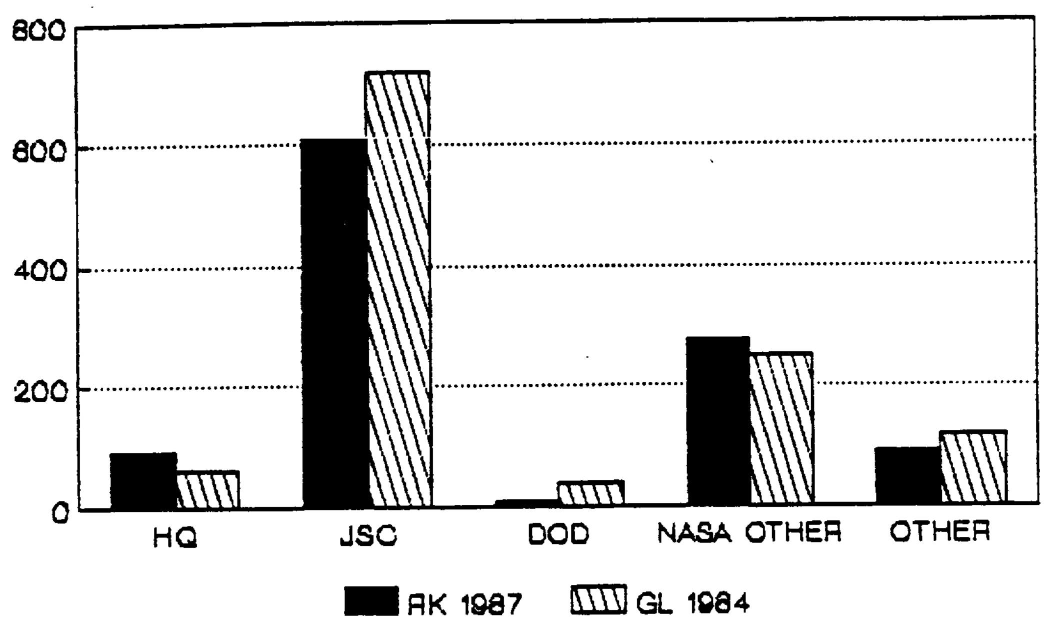


CHART 5

TIME OF MEETINGS

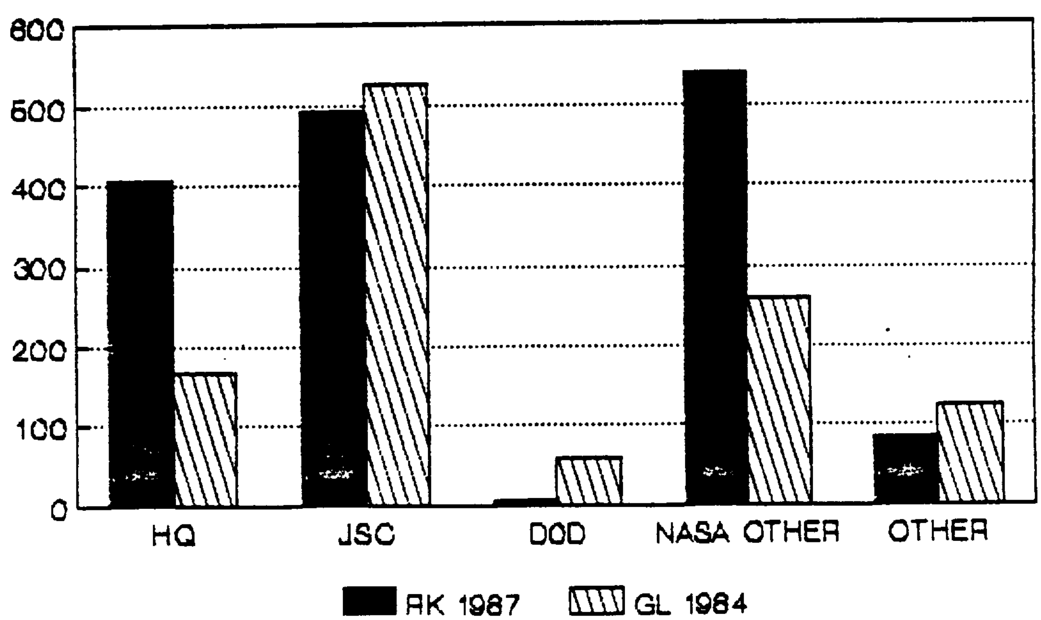


CHART 6

SUBJECT
NUMBER OF MEETINGS

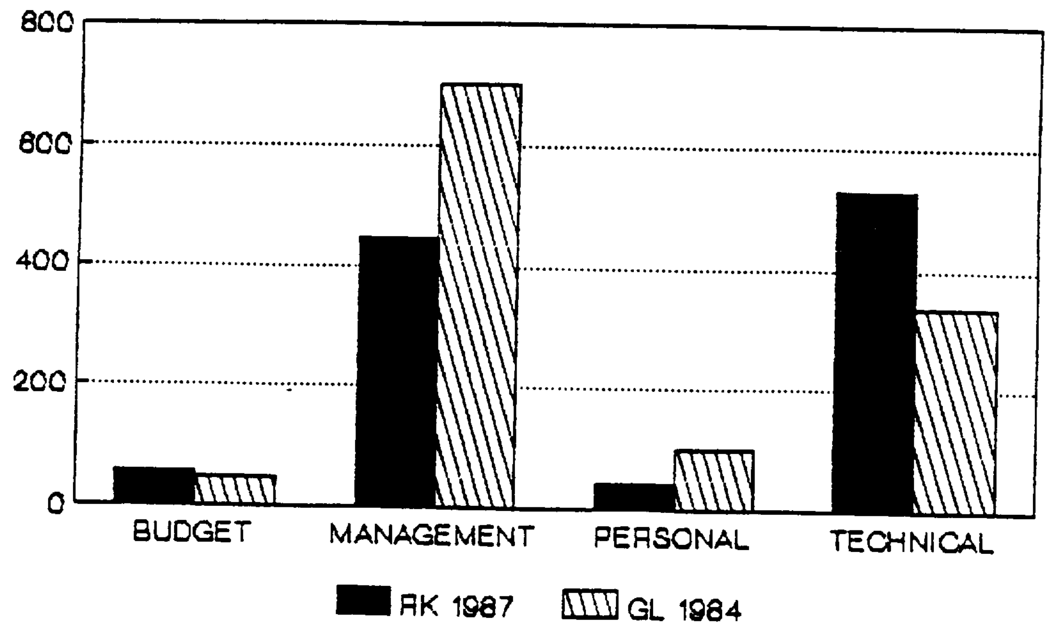


CHART 7

TIME OF MEETINGS

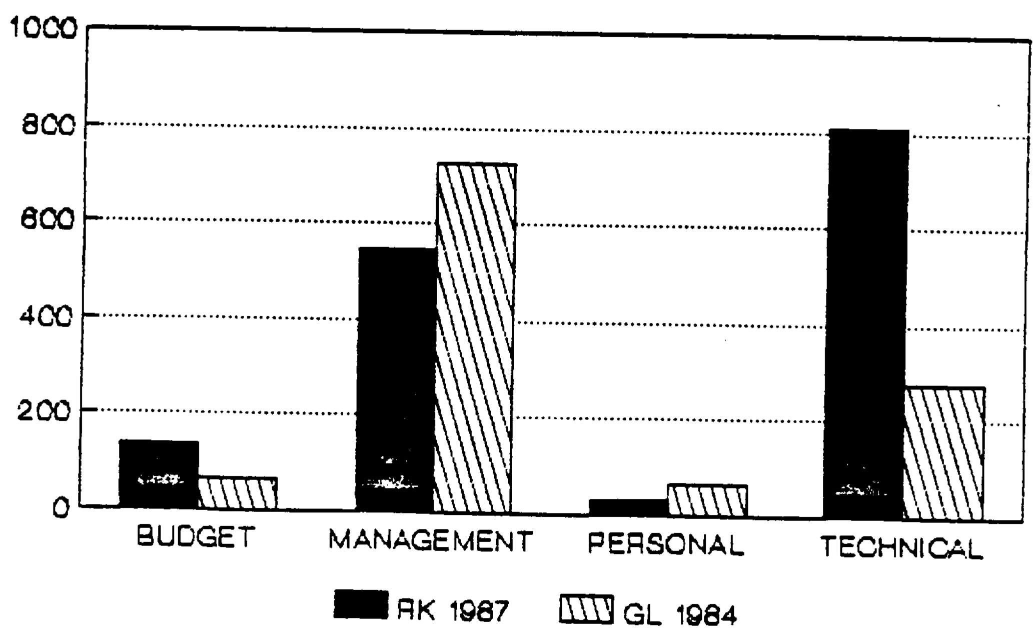


CHART 8

AGENDA SUMMARY COMPARISON CHART
RK/1987 TO GL/1984
BY MAJOR CATEGORY

	RK	GL
NUMBER OF OBSERVATIONS	1073	1184
TOTAL TIME	1524 HRS.	1134 HRS.
AVG. TIME/OBSERVATION	1.42 HRS.	0.96 HRS.

LEVEL

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
ACROSS	RK	136	13	158.25	10	1.16
	GL	381	32	553.50	49	1.45
DOWN	RK	797	74	903.50	59	1.13
	GL	693	59	395.00	35	0.57
UP	RK	140	13	463.25	30	3.31
	GL	110	9	185.50	16	1.69

TIME FRAME

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
FUTURE	RK	71	7	131.75	9	1.86
	GL	135	11	176.25	16	1.31
NOW	RK	1001	93	1392.75	91	1.39
	GL	1045	88	952.25	84	0.91
PAST	RK	1	<1	.50	<1	0.50
	GL	4	<1	5.50	<1	1.38

LOCATION

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
DOD	RK	6	1	5.75	<1	0.96
	GL	40	3	58.00	5	1.45
HQ	RK	90	8	406.75	27	4.52
	GL	62	5	167.75	15	2.71
JSC	RK	609	57	491.00	32	0.81
	GL	717	61	523.75	46	0.73
N. OTH	RK	275	26	537.25	35	1.95
	GL	247	21	260.50	23	1.05
OTHER	RK	93	9	84.25	6	0.91
	GL	118	10	124.00	11	1.05

SUBJECT

		NUMBER		TIME		AVG TIME
		NO.	(%)	HRS.	(%)	HRS.
BUDGET	RK	57	5	136.25	9	2.39
	GL	45	4	62.75	6	1.39
MGMT.	RK	444	41	547.00	36	1.23
	GL	702	59	727.00	64	1.04
PERS.	RK	43	4	30.50	2	0.71
	GL	100	8	66.25	6	0.66
TECH.	RK	529	49	811.25	53	1.53
	GL	337	28	278.00	24	0.82

APPENDIX III D

TENTATIVE OUTLINE FOR THE INVESTIGATION INTO ALTERNATIVE MANAGEMENT STYLES

APPENDIX III D

TENTATIVE OUTLINE FOR INVESTIGATION INTO ALTERNATIVE MANAGEMENT STYLES

1. WHAT IS THE BASIC ISSUE?

NASA needs alternative ideas on designing a large complex product with high visibility and risk and then bringing that product to an operational stage and maintaining it. The accent, here, is on operations. They do not need help on the preliminary design stage but rather on the control and development of the operational stage and the transition between.

2. HOW DOES NASA DO BUSINESS DIFFERENT FROM OTHER ORGANIZATIONS?

A. Little competitive pressure.

B. Heads never roll.

C. Poorly defined goals or mission.

D. Diffused lines of authority.

E. Utilizes a large number of contract people. In fact, the primary function of NASA management is, to some degree, that of controlling the efforts of others.

F. Public sector, public control, public exposure.

G. Little accountability for cost control.

H. Extremely high visibility along with public exposure of all work and work practices.

I. Unique product with high cost and high risk.

J. Federal regulations constrain work as does public funding.

K. Projects are not let by determining specs and letting contract. NASA tends to want to manage contract from end to end. This includes a large number of spec or design changes.

L. DOD involvement sometimes leads to two masters of one project.

3. TYPES OF BUSINESS THAT NASA NEEDS TO EXAMINE.

A. Those that must quickly develop and bring products to market.

B. Those that manage extremely large and complex systems.

C. Those that manage a highly technical system which approaches state of the art and which has a large amount of change in the product during the early production phase.

4. TYPICAL QUESTIONS THAT MIGHT BE ASKED.

DEMAND FORECASTING

1. How is demand for the product determined?
2. Is the company innovative in its product development, or does it respond to market forces?
3. Who is responsible for demand forecasting?
4. What types of forecasts are done (i.e., market, financial, sales, production)?

OPERATIONS PLANNING

1. Is there cooperation between the company and its vendors? If so, what is the extent of this cooperation and how is it managed?
2. Who determines process standards and how?
3. How is rework handled?
4. Are "Zero Defects" programs in place and if so how do they work?
5. Is there a strong utilization of outside contractors for subassemblies as part of the parts procurement process and if so how are costs contained?
6. On what time frame is the planning done (i.e., short, medium, long term). Are Master schedules used? How is shop floor production handled in regards to schedules?
7. What approaches to scheduling are used (analytical, iterative, heuristic, charting, simulation, etc.)?

INVENTORY PLANNING AND CONTROL

1. Is JIT, MRP, or some other conventional system of inventory control used? What type of inventory model is used (i.e., fixed order size, EOQ, etc.)
2. What type of procurement control system is used?

DISPATCHING AND PROCESS CONTROL

1. How is data acquired from the shop floor? How is it distributed and to whom? What kind of data?
2. How is corrective action taken for off-schedule work?
3. What is the policy for products damaged by workers?
4. What types of control procedures are in place to monitor progress and to correct poor performance?

QC

1. How is QC done, what methods are used?
2. How is the QC program administered?
3. Are incentive or other motivational plans in place to reduce scrap and rework?

HUMAN RESOURCE MANAGEMENT

1. What types of HRM policies are in effect to attract, motivate, and retain employees?
2. How is innovation induced and fostered?
3. How are new employees recruited, selected, and trained?

BUDGETARY (FISCAL) POLICY

1. What type of cost control policies and procedures are in effect?

2. How are costs apportioned (i.e., direct labor, overhead, cost centers, etc.)?

3. What economic criterion or method is used to evaluate future projects?

CHANGE CONTROL

1. How is change in the product managed?

2. What types of product specifications are used?

THE PATH FROM DESIGN TO PRODUCTION

1. Was computer simulation used to discover problems?

2. Were people from operations involved in the design and production stage?

3. What sort of organizational structure was set up to smooth the path to production?

4. What types of people were necessary at each of the stages from design to production?

BACKGROUND INFORMATION

1. Does the company use job descriptions and, if so, at what levels?

2. What type of evaluation procedure is used for the personnel at each level?

3. How is movement in the organization for star performers managed?

4. What types of training programs are in place?

APPENDIX III E

COMPARTMENTALIZATION

INCREASING THE FLIGHT RATE
COMPARTMENTALIZATION
JLH-10 MAY 88

ASSUMPTION 1: To a large degree, the schedule is driven by the manifest, i.e., aberrations in the schedule are ofttimes caused by manifest changes.
ASSUMPTION 2: If the shuttle program is ever to be operational, in the sense that it is driven by time and cost as well as safety, then the processing procedure must be robust enough to deal with late manifest changes.
ASSUMPTION 3: A large amount of the processing is mission unique.
ASSUMPTION 4: Much of what is contained herein has already been conceptualized by others at NASA.

INTRODUCTION: In order to increase the flight rate, a means must be found of working smarter, not harder. The **only viable** way to do this is to reduce the amount of processing items which are mission unique. Training is a good example. Training now takes 11 to 12 weeks and much of it is mission unique. This 11 to 12 week period occurs immediately prior to launch. This forces the schedule to be unresponsive to any manifest change in the last 3 months of processing. There is absolutely no way the shuttle will be able to maintain a high flight rate (12 to 15 per year or more) unless the schedule is robust up to a very short time (one month ?) before launch. The only way to get robustness is to reduce variability in the sense of mission unique items. Since mission is driven by manifest, this requires that the variability in the manifest must be reduced. Note that this is different than saying that the manifest must not be changed. The schedule must be responsive to manifest changes. The implication here is that difference between payloads must be reduced. This leads to compartmentalization.

DISCUSSION: The procedure at this point is to examine all the payloads that have flown in the last several years and are likely to fly in the next several years. Parameters which determine a payload are listed with concentration on those that affect shuttle processing. This effort needs to be done with involvement from the payload community (the customers). This list then needs to be approached with the intent of placing payloads into compartments. The idea is to design processing packages of the shuttle around similar payload packages. There will be some payloads which do not fit with others. A compartment is created for them. Price incentives and early launch considerations can be used to influence the customer community to fall within one of the standard compartments as opposed to the unique compartment. Even a scientist, if he can fly cheaper or quicker, will conform to reasonable restrictions.

PROCESS: 1) Determine an OPR.

2) Decide on the amount of robustness to include in the schedule. I suggest that a target of one month be the initial value. This means that the intent should be to eventually allow manifest changes up to one month from launch.

3) A working group under the OPR with very high level influence needs to develop the payload list of parameters and determine the compartments. Five standard compartments and one unique department is a good target.

4) Once a set of compartments is determined, processing packages need to be built around all of the compartments.

5) The process needs to be reviewed periodically to insure that the packages continue to meet the needs of the customer community.

6) This activity has a long lead time. However, nothing serious is going to be done about increasing the flight rate until this activity or something similar is done. For this reason I encourage this process to be undertaken at the earliest possible date.

APPENDIX III F

LAUNCH PREDICTIONS FOR STS-26

LAUNCH PREDICTIONS
STS 26
JLH 11 OCT 88

INTRODUCTION:

In early July, 1987 a survey was started to predict the time of the launch of STS-26. Eight people were chosen from the Program Office of the shuttle to estimate the approximate time of the next launch. Later, for the mid-September prediction and subsequent ones, this number was expanded to include 10 people. With this exception, the same people were used for all surveys. Data was gathered on two month intervals for the middles of July 87, September 87, November 87, January 88, March 88, and May 88. The survey was halted in mid May as it was felt that the launch was close and the probabilistic nature of the survey would change.

RESULTS:

The results of this survey are shown on a bi-monthly basis in the following table and in the included charts.

Time of Prediction	Most Likely Month	50/50 Point
Mid-July 87	August	9.5
Mid-Sept. 87	August	9.8
Mid-Nov. 87	August or September	9.8
Mid-Jan. 88	August or October	9.9
Mid-March 88	August or October	9.9
Mid-May 88	October	10.0

In the table, the most likely month refers to the month chosen most often by the respondents. The 50/50 point refers to the point which represents the mean of the distribution. The mean of a distribution is, of course, the point where is a probability of 0.5 of lying to the left and a probability of 0.5 of lying to the right. The number in this column represents the month and a decimal fraction of a month. As an example, 9.9 represents the end of September.

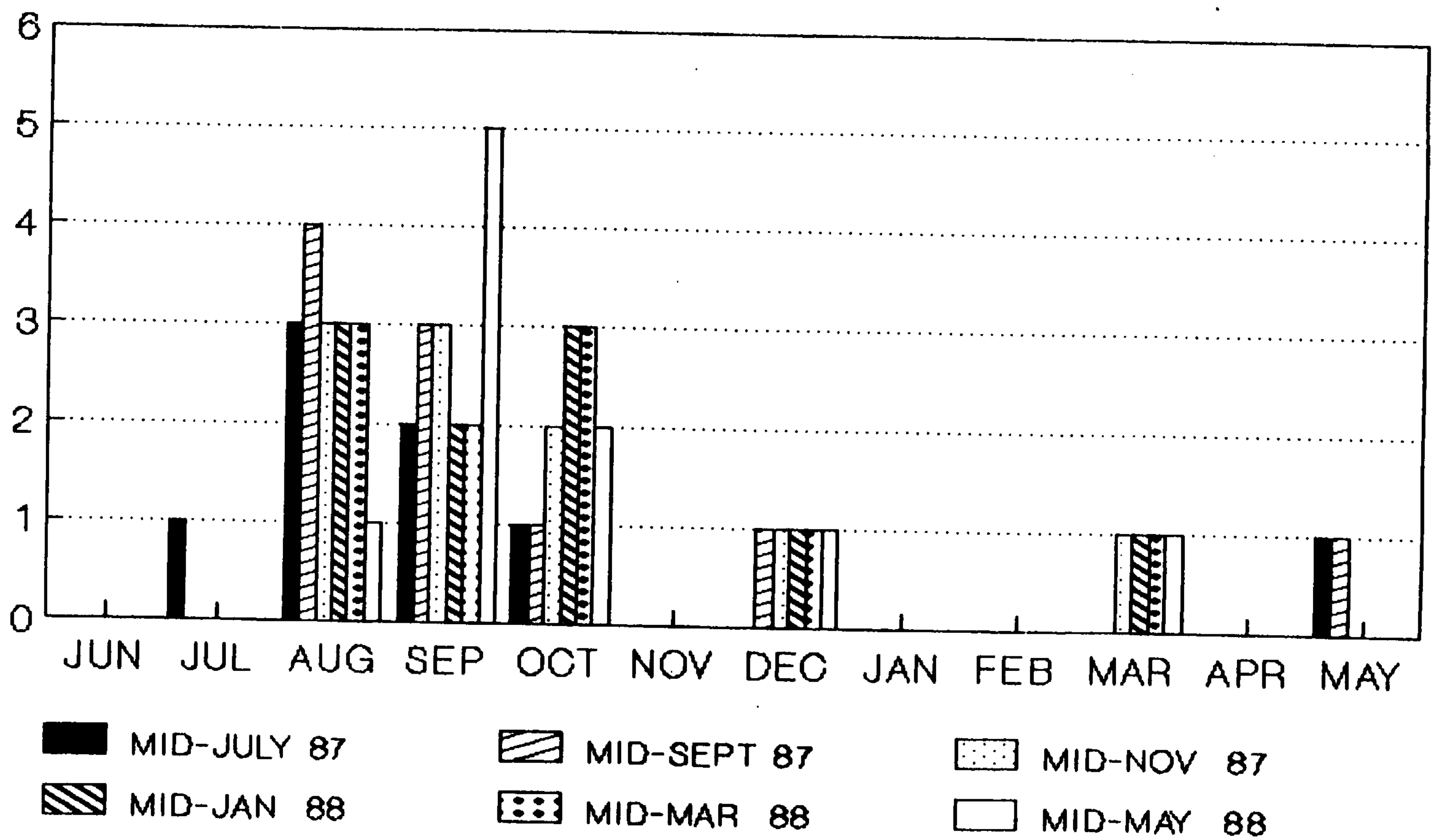
The charts are two different representations of the bi-monthly distribution: a bar chart and a curve fitted chart. The curve fitted chart is fitted by HPG software and shows the trending of the distributions to the right, or later in the year, over the life of the survey.

CONCLUSIONS:

As has already been mentioned, the distributions slowly moved to the right. However, at March, the group had narrowed in on late September or early October. Even though the group picked October as the most likely month for launch in their latest prediction, the survey still showed a remarkable degree of accuracy. The launch occurred on September 29, 1988 and the final mean was 10.0.

As a final comment, either this method of prediction was fairly accurate or there was a large amount of luck in the survey. Given that the survey was accurate, a reasonable conclusion is that there is a fair amount of collective knowledge in the program office which statistical methods can use to reduce uncertainty of highly probable events.

LAUNCH PREDICTIONS
STS 26



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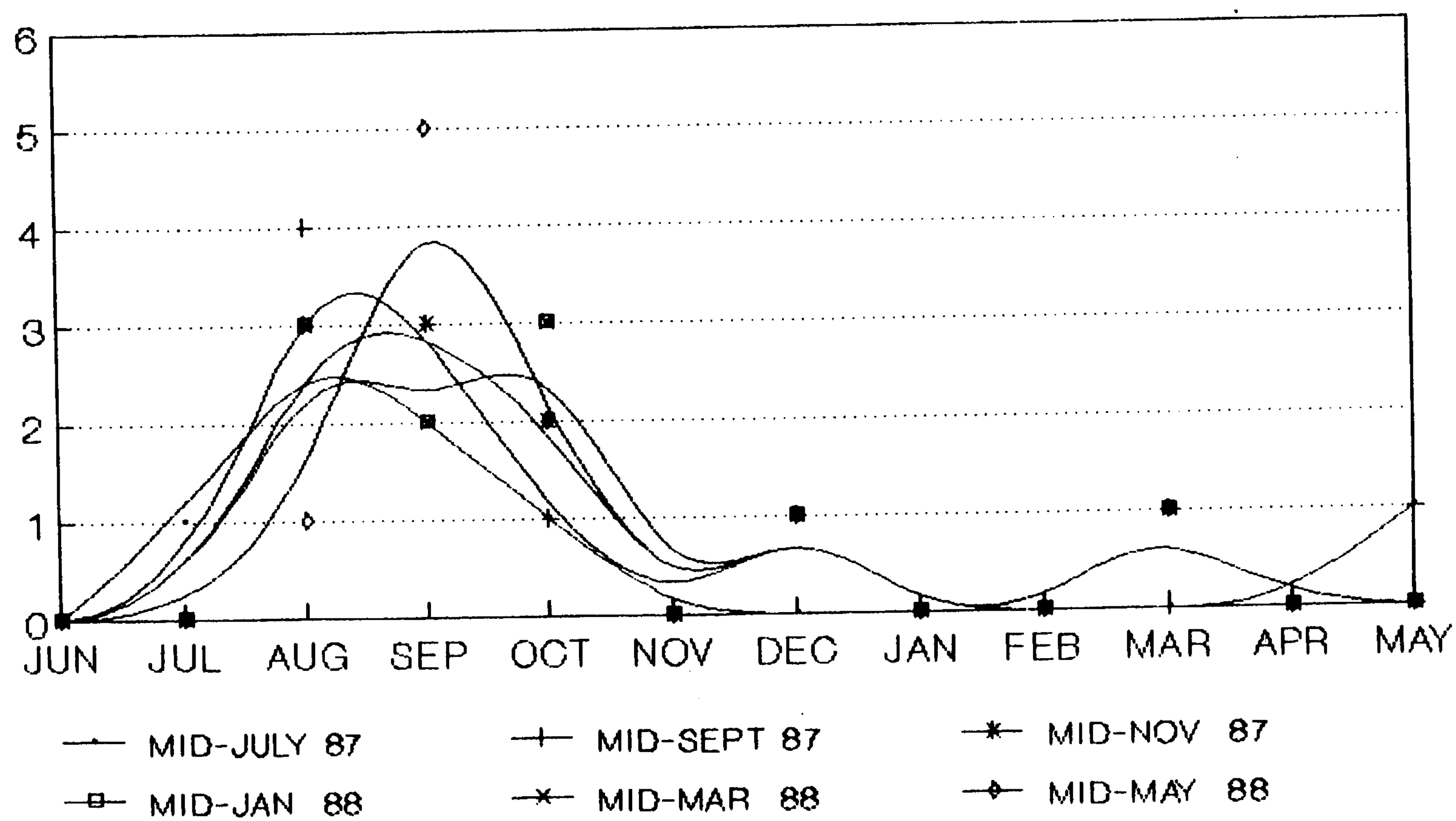
LAUNCH PREDICTIONS

STS 26



HOW DID YOU DO?

Congratulations to the launch prediction team. The mean of your final guess was month 10.0 and the launch occurred on month 9.97 (September 29). As an interesting phenomenon, to a man, each of you swore you never changed your prediction (with the exception of a few stout hearts who owned up to moving in the last prediction). However, the distribution slowly but surely moved to the right throughout the process. Since I do not keep records of who estimated what, but rather that an estimation was made, I can not verify your claim. So I will assume that you remained constant and it was someone else that moved.

The use of your prediction is indicated in the enclosed broadside which was furnished to D. Kohrs. There were interim reports which were also furnished to sample the feelings about launch date.

Now we will see how good you really are and whether you can bring it off twice. I am in the process of designing a new survey about the sustained obtainment of a high flight rate. The estimates on this survey will be six months apart and deal with the quarter and year when you feel that the shuttle program will be capable of obtaining a rate of 14 flights per year and maintaining that rate. Note that this is different than actually flying 14 but rather deals with the ability to fly 14 and the ability to do so repeatedly. So in essence, we are gauging when we feel the program is ready.

The amount of uncertainty in this question is greater than the last survey so I wished to warn you ahead of time. I will be around sometime in December to get your first reaction.

Thanks again for your help

John Hunsucker

APPENDIX III G

LESSONS LEARNED

LESSONS LEARNED
JLH 18 OCT 88

ASSUMPTION 1: The shuttle is a unique and complex vehicle which is highly developmental in nature.
ASSUMPTION 2: The public exposure of the shuttle and the shuttle program is an important variable to consider in the management of the shuttle.
ASSUMPTION 3: Because of the complexity and uniqueness of the shuttle, there is some probability that a major accident will occur to the vehicle, its crew, or its mission.
ASSUMPTION 4: Most programs that NASA develops will be more similar to the shuttle in regards to the first three assumptions than they are different.

DISCUSSION: Given the four assumptions above, it would seem to be a valuable utilization of resources to consider developing a lessons learned document based on the experience that the shuttle program management went through in recovering from the Challenger accident. While the Roger's Commission report may well document the incidents preceding the accident, it will do little to describe how management dealt with the aftermath of the accident. The following are types of questions or subjects which deal with information which might be valuable in the future.

1. Which offices were most involved with the recovery effort?
2. What was the manpower expenditure used in the recovery effort? How was the manpower used? What percentage of available manpower was used?
3. What lessons were learned in dealing with the Roger's Commission, the NRC, and other investigatory or over sight organizations?
4. What tasks were performed but were not a reasonable expenditure of resource? What should have been done but was not?
5. What major surprises in the utilization of resources came about as a result of reflight issues? What went exactly as expected?
6. What factors influenced the length of the reflight time? How could the time have been shortened?
7. How much did the program suffer due to the use of resources on the reflight issues, i.e., what tasks that needed doing went undone due to the use of resource on reflight issues?
8. Given that the accident and the reflight issues set the program back in time, was there a way that the amount of setback could have been reduced? As an example, would the appointment of a reflight "czar" to direct the reflight effort have reduced the amount of setback? This might have allowed top management to concentrate on normal issues while monitoring the reflight effort and insuring that the program moved forward.

SUGGESTIONS: If this topic is of interest, then the first step is to determine the right set of questions. Next, the group has to be chosen to respond to the questions. Then, an editor must be picked to assemble, edit, and rewrite the answers. As part of this process, an office of primary responsibility should be chosen. The last step is to have the final document reviewed by top level management for its authenticity and its applicability.

APPENDIX III H

COORDINATION THEORY

APPENDIX III H

COORDINATION THEORY

Szilagyi, Andrew D., Jr. (U of H), and Marc J. Wallace, Jr., Organizational Behavior and Performance, 3rd Ed., Scott, Foresman and Company, 1983.

Three intergroup coordination factors or characteristics of interdependence, task uncertainty, and differentiation (time and goal orientation) establish **three managerial coordination requirements** that can influence **intergroup performance.**

Interdependence -- the degree to which the interactions between the groups must be coordinated to attain a desired level of performance. Three types of interdependence are discussed: pooled; sequential; and reciprocal.

Pooled: groups are independent of each other, but each renders a discrete contribution to the larger organization and is supported by the organization. (i.e. diff't GM groups: Chevrolet, Cadillac, etc.). Low degree of dependence.

Sequential: outputs of one group are inputs to another. Moderate degree of dependence.

Reciprocal: certain outputs of each group become inputs for other groups, or to each other. High degree of dependence.

Task Uncertainty -- varies with two factors: task clarity and task environment.

Task Clarity: the degree to which the requirements and responsibilities in the group are clearly stated and understood.

Task Environment: factors or elements, internal or external to the organization, that are relevant or can affect the level of performance of a unit or group.

Szilagyi, Andrew D., Jr. (U of H), and Marc J. Wallace, Jr., Organizational Behavior and Performance, 3rd Ed., Scott, Foresman and Company, 1983. (Continued).

Time and Goal Orientation -- generally influence intergroup performance.

Time Orientation: time span required to obtain information or results relating to the performance of a task.

Goal Orientation: focuses on the particular set of task objectives or goals that are of major concern to individuals in organizations.

STRATEGIES FOR MANAGING INTERGROUP PERFORMANCE

HIGH	
:	
:	Integrating departments
:	
:	Teams
:	
:	Task Forces
Intergroup Performance Requirements	Liaison or internal boundary-spanning roles
:	Planning
:	
:	Hierarchy
:	
:	Rules and procedures
:	
LOW	

Mascarenhas, Briance (Rice U.), "The Coordination of Manufacturing Interdependence in Multinational Companies", _Journal of International Business Studies,_ Winter 1984.

Used the following coordination methods that reflect the basic March and Simon classification:

Impersonal Methods -- the use of legitimate methods universally distributed in the company that do not require verbal interaction between individuals. Examples are: standard operating procedures, deadlines, regular reports, budgets, predetermined work plans, and schedules.

System-Sensitivity -- the ability of subunit members to foresee the impact of other subunits of actions taken in one subunit and thereby to undertake appropriate behavior that avoids system suboptimization problems. This system-sensitivity tends to be acquired through a process of socialization of the members of the organization, and is a function of the recruitment process, training programs, and international transfers.

Compensation System -- the use of a reward system that does not encourage key subunit members to pursue the parochial interests of their own subunit at the expense of the rest of the organization.

Personal Communication -- the use of communication and feedback involving verbal interaction between individuals, such as group meetings, telephone conversations, and face-to-face communication.

Thompson, James D., <u>Organizations in Action,</u> McGraw-Hill, 1967.

Coordination -- In a situation of interdependence, concerted action comes about through coordination; and if there are different types of interdependence, [they] would expect to find different (three) devices for achieving coordination. The work of March and Simon (1958) is particularly useful for this purpose, although [they have tampered] with their labels.

The three devices are: **Standardization; Coordination By Plan; and Coordination By Mutual Adjustment.**

Standardization: involves the establishment of routines or rules which constrain action of each unit. (Requires stability and repetitivity in environment).

Coordination By Plan: establishment of schedules for the interdependent units by which their actions may then be governed. (Doesn't require high degree of stability as in Standardization).

Coordination By Mutual Adjustment: involves the transmission of new information during the process of action. (The more variable and unpredictable the situation, the greater the reliance on coordination by mutual adjustment [March and Simon]).

Hampton, David R., Summer, Charles E., and Webber, Ross A., Organizational Behavior and the Practice of Management, 3rd Ed., Scott, Foresman and Company, 1978.

This OB book, although not concentrating on Coordination Theory in any one place, indicates that coordination is useful, if not necessary, in many facets of the organization.

Coordination for Structure and Behavior: pp. 320 - 326.

Coordination for Product Innovation: pp. 332 - 343.

Coordination for Management and Technology: pp. 344 - 353.

Nachane, D. M., "Optimization Methods In Multilevel Systems: A Methodological Survey", European Journal Of Operation Research, 1984.

This paper addresses the problem of optimizing static and dynamic multilevel systems using coordination principles such as the Interaction Prediction Principle, the Interaction Balance Principle, the Interaction Estimation Principle, Load Type Coordination Principle, and Coalition Type Coordination Principle.

Static and dynamic systems are defined and algorithms based on one, or a combination, of these principles are suggested for the optimization of such systems. The working of these methods is illustrated and the computational aspects of each technique are discussed. The author also briefly discusses the case of uncertain systems where some parameters are unknown. He then offers an overview of the main areas where multilevel techniques have been applied.

The methods presented in this paper offer the advantage of being applicable to various disciplines. The paper is mainly a review of the optimiztion techniques and an incentive for the application of these techniques in other areas.

Cray, David, "Control And Coordination In Multinational Corporations", *Journal Of International Business Studies*, 1984.

This paper reports the results of a study on the integration process in multinational corporations. It examines several factors associated with the degree of integration, and studies the relationship between two processes of integration: coordination and control. The author defines both processes and discusses the relationship between them. The factors examined (organizational structure, technology, foriegn commitment, financial performance, and nationality) are related to the use of coordination and control in order to investigate a theory linking the use of these two processes to the need for predictability, flexibility, and cost.

The main results of the study are:

1. Coordination and control vary together but their association is not overwhelming.

2. Control is more reactive than coordination to the structural characteristics of size and location in the corporate structure.

3. There is a strong association with both dimensions of coordination for the technology and foreign commitment variables. These associations are weak for control.

4. There is an association of equal strength with both coordination and control for profitability.

From these results, the following conclusion are drawn:

1. Few variables that are thought to affect patterns of integration also affect coordination and control, which then represent separate solutions to the integration problem.

2. Control is more responsive to contingencies faced by the subsidiary while coordination is more responsive to the complexity of the overall system.

The author concludes the article by stating that the result of this study should hold for any large organization with geographically dispersed subunits. However, the degree to which the theory is applicable depends on the particular organization.

Van De Ven, Andrew H., Delbeco, Andre L., and Koenig, Richard, "Determinants Of Coordination Modes Within Organizations", American Sociological Review, 1976.

This paper studies the coordination process by studying some key propositions in the literature about coordination at the work unit. It classifies mechanisms of coordination into impersonal, personal, and group modes. It then investigates the extent to which the variation of the three modes is predicted by task uncertainty, task interdependence, and unit size.

The paper intorduces the two general ways in which organizations can be coordinated: by programming and by feedback. Given that combinations for coordination in each mode are often used to achieve integration of a collective set of activities, the authors address the question of identifying the situation factors that determine the appropriate combination of mechanisms to use. This research examines three factor: task uncertainty, task interdependence, and unit size.

The main results and conclusions of the research were:

1. As the unit size increases, the use of impersonal coordination decreases significantly, and the use of hierarchy increases to a smaller degree. The use of horizontal channels and group meetings remains the same.

2. With the increase in flow interdependence among unit members, the use of impersonal and personal coordination mechanisms remains invariant. There is a significant increase in group coordination.

The factors studied show that not only is there a difference in the degree of influence of the three factors on the use of coordination mechanisms, but also a difference in the kind of influence of each factor is apparent.

The last part of the discussion is an evaluation of the comparative strengths of the three factors in explaining variations in the coordination process.

This article is a good introduction to the process and the mechanisms of coordination. The results, however, are limited to the work unit or departmental level within a large employment security agency. On the other hand, the results can be used as a starting point for investigating the use of alternative mechanisms for coordination across work units and levels within organiztions.

CHAPTER IV

STATISTICS FOR MANAGERIAL DECISION MAKING

IV. STATISTICS FOR MANAGERIAL DECISION MAKING

1.0 INTRODUCTION AND BACKGROUND

The focus of this chapter deals with the integration of statistics into the managerial decision making process at JSC. Decision making, or decision analysis, in many instances relies on the use of statistics to determine optimum solutions for chosing alternatives. If statistics is used incorrectly when given a set of choices, then sub-desirable, or even undesirable, decisions may be reached given a set of choices. Many times statistical information is merely presented to managers for their approval or inspection. It is necessary that the managers are able to interpret statistical results and/or ask pertinent questions regarding the statistical information.

There are several complicating factors regarding the use of statistics in the decision making process of the shuttle program. One is that many of the managers are from an educational era that did not require statistical coursework. Another is that statistics has been used, at most, sparingly in the development and operation of the shuttle for many reasons, most of which are valid. There is a very small, relatively speaking, data base on which to make statistical conclusions for the shuttle and its components. This last fact, along with intervention by groups such as NRC, is forcing the use of methods on the forefront of research in

statistical decision making. Many of these methods, such as Bayesian decision theory, are still controversial. Methodology from the nuclear power industry, with a much larger data base, is moving into the aerospace arena. All of these complicate the statistical decision process for the shuttle. In some sense, statistical decision making is a new way of life for shuttle managers.

2.0 DISCUSSION

Managers at JSC, in a move to become more operational, will start having to make an increasingly larger number of decisions based on the proper interpretations of statistics. As more flights are achieved, the size of the data base will grow. As the flight rate increases, the use of statistics will become more necessary to control the process. During the previous year, problems directly related to decision making based on the use of statistics arose at the upper levels in the program office. Two broadsides of such instances are given in the Appendix to this chapter. Appendix IV A contains a discussion on a memo regarding the "STS Ambient Temperature Launch Commit Criteria Statistics for KSC" by Computer Science Corporation. One point of discussion pertains to the interpretation of the information. Specifically, the statistical information seems ambiguous. Realizing the ambiguity of the information is the type of process with which managers need familiarity. Appendix IV B

contains a discussion on a manual regarding the determinations of "Expectations For Future Events" using Mission Assurance Probability (MAP) from Advanced Research Technology Systems. If MAP is to be used with the space shuttle program, necessary precautions should be made for determining the reliability of the application prior to use. Both of these situations required managers to understand the statistical information and processes contained therein.

As a result of these considerations, a short course designed to assist upper level managers was developed to aid in the use of statistics in decision making. In particular, the course was designed to help managers interpret statistical results and to determine the types of questions which should be asked when they are presented with statistical information. The course developed is designed as a 12 hour course divided into six 2-hour sessions and taught by Dr. J.L. Hunsucker. As of December 1988, 3 of the 2-hour sessions were taught.

3.0 CONCLUSIONS AND RECOMMENDATIONS

It is our recommendation that the statistics short course be continued in the upcoming year. In addition, this course, or a similar one, should be offered to a larger audience including middle level managers.

APPENDIX IV A

A DISCUSSION ON THE STS TEMPERATURE LAUNCH COMMIT CRITERIA STATISTICS FOR KSC

DISCUSSION

STS Ambient Temperature Launch Commit Criteria Statistics for KSC, Memo from ED44/Kelly Hill

JLH 23 Oct 88

The data in the memo was developed by Orville Smith who evidently is a contract employee for ED44 and works for Computer Science Corporation. On talking on the phone with both Mr. Hill and Mr. Smith it was determined that the data presented is all historic data. In this sense there was no statistical analysis done anywhere. Specifically, Tables 1-9 were compiled by examining historic data and counting the out of tolerance events. Without these Tables the memo is very difficult to understand. From the Tables, Figures 3, 4, 5, and 6 were developed.

One of the important results of this memo is that the restriction on ambient temperature are ambiguous as written, (page 2, next to last paragraph of the memo). In fact the memo seems to also be ambiguous in its interpretation of the constraint. The following table shows the constraints B.2 and B.3 as cited from Revision D JSC 16007 Section 1.4.1 as quoted in the memo and the memo interpretation of the constraint.

16007		memo interpretation	
Temperature T	Wind Speed W (knots)	Temperature T	Wind Speed W (knots)
T <= 37 deg F	W > 5	T <= 37 deg F	any W
T < 47 deg F	W < 5	37 < T <= 47 F	W < 5

Both interpretations seem to have mixed up a constraint with the temperature with an acceptable condition with the wind or vice versa. One would suppose that the real constraint is something like:

T < = 37 any W

37 < T <= 47 W > 5

Which of course brings up the question as to the constraint with T > 47. Perhaps a better way to write the constraints would be to list the temperature ranges from < 37 to > 99 and the resulting wind speeds which impose a constraint.

Since the Table in the memo were based on the interpretation of the constraints, the question arises as to exactly what was counted in the Tables. Perhaps the memo should be redone after the constraints are rewritten.

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National Aeronautics and
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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812

NASA

Reply to Attn of: ED44-(128-88)

October 12, 1988

TO: JSC/~~WE~~/Lambert Austin WE2

FROM: ED44/Kelly Hill

SUBJECT: STS Ambient Temperature Launch Commit Criteria Statistics for KSC

The purpose of this memorandum is to present a statistical analysis on the occurrence of STS launch commit criteria for ambient temperature and ground wind launch wind constraint. The ground wind launch constraint is defined by the occurrence of either the lift-off wind or the RTLS runway wind constraints (see Figure 2). Reference related documents: (1) Memorandum MSFC ED44-(64-88), July 14, 1988, "STS: FRF, Lift-off And RTLS Runway Wind Constraint Statistics For KSC," and (2) MSFC ED44-(101-88), August 30, 1988, "Peak Wind Speed 60 ft. Reference Level Versus Exposure Period, KSC."

Following a review of the documented ambient temperature restrictions, a launch constraint is defined for the purpose of this memorandum as the ET chill constraint which involves certain limits on ambient temperatures with wind speed (Figure 1).

The most significant results from this analysis with respect to the ET chill constraint occurrence at KSC are:

(1) The constraint is violated only during the months of November to May with the most frequent occurrence in December, January and February (Tables 1, 2, 3).

(2) Worst hours (local standard time at KSC are Eastern Standard Time) for constraint violation are from midnight to noon with probability of occurrence varying from 6 to 10 percent during the winter months (Table 3).

(3) During the winter months the ground wind constraint has the least frequent occurrence during the period from midnight to noon (Table 4).

01

(4) A comparison of the probability for each constraint (ET chill and ground wind) and the occurrence for the two constraints combined are illustrated for February in Figures 3, 4, and 5. The best time of day for launch for the two constraints combined during the winter months is near 1800 hours.

1.0 <u>The Launch Commit Criteria</u>

This memorandum presents a statistical analysis on the occurrence of two STS launch commit criteria for KSC. They are: ambient temperature restrictions and the ground wind launch constraint; where the ground wind launch constraint is defined by the occurrence of either the lift-off wind constraint or the RTLS runway wind constraint (see Figure 2).

1.1 The Ambient Temperature Restrictions:

The ambient temperature restrictions as quoted from JSC document JSC 1600 Section 1.4.1 are:

A. Prior to External Tank Cryogenic Loading.
Propellant loading of the External Tank shall not be initiated if the 24 hour average temperature for the preceding 24 hours has been below 41 degrees Fahrenheit.

B. From Start of ET Cryogenic Loading to Launch.
The countdown shall not be continued nor the Shuttle launched if the ambient temperature during this time period exceeds (sic) any of the following criteria for more than 30 minutes:

(1) Maximum temperature of 99 degrees Fahrenheit.
(2) Minimum temperature of 37 degrees Fahrenheit for wind conditions at or above 5 knots. (sic)
(3) Minimum temperature of 47 degrees Fahrenheit for steady state wind conditions below 5 knots. (sic)

As written, this launch constraint, 1.4.1 B (2) and (3), is ambiguous. The lead-in statement for this criteria requires that these temperature values be exceeded. The inequalities are not correct. The terms maximum and minimum temperature have specific meanings such as the highest temperature and the lowest temperature during a specified time period: For example, the daily maximum temperature and the daily minimum temperature.

The interpretation of the criteria containing the relationship between ambient temperature and wind used for this memorandum is as follows: The constraint is (see Figure 1) for ambient

temperature > 37 to ≤ 47 degree Fahrenheit (deg. F) with wind < 5 knots or ambient temperature ≤ 37 deg F with any wind speed; where the wind is the steady state wind speed referenced to the 60 foot level above natural grade. This condition must exist for 30 or more consecutive minutes before this criteria is violated. In the referenced document, no rationale is given for this operating constraint. However, for the purpose of this memorandum the combination for ambient temperature with wind (Figure 1) is referred to as the ET chill effects on the SRB constraint or, in short, the "ET - chill constraint".

1.2 The Ground Wind Launch Constraint:
The occurrence of either the lift-off or the RTLS runway wind constraint is considered as the ground wind launch constraint (see Figure 2), where the lift-off wind constraint and the RTLS runway wind constraints are defined as follows:

1.2.1 Lift-Off Wind Constraint
The lift-off wind constraint is defined as the peak wind speed at the 60-foot reference level ≥ 17 knots from the south ± 30 degrees, and ≥ 24 knots from all other directions. This constraint is due to the current SRB aft-skirt structural wind load limit at lift-off.

1.2.2 RTLS Runway Wind Constraint
The RTLS Runway wind constraint is defined by the wind components relative to the runway. These wind components are derived from the peak wind vectors at the 30-foot reference level. The cross runway component constraint is ≥ 12 knots. The tailwind component constraint is ≥ 10 knots. The headwind component constraint is ≥ 25 knots. Because both ends of the runway are used for this analysis, there is no tailwind constraint. Therefore, the headwind component is the wind component parallel to the runway (see Figure 2). If either the crosswind limit or the parallel wind component limit occurs, this condition is counted as a violation of the RTLS wind constraint. This RTLS runway wind placard is based on the STS landing gear and tire load limits and flight controllability for touch-down.

2.0 <u>Analysis</u>
From historical weather records, atmospheric measurements and observations are available only at hourly intervals. Therefore, any meteorological operating constraint that requires continuous measurements cannot be exactly duplicated. The main limitation in this statistical analysis is the requirement for the ET chill temperature with wind combination to have a duration for 30 or more minutes. To partially overcome this limitation, the

analysis is made for the occurrence of this condition for at least one time and for at least two times during a 9 hour exposure period. It is further assumed that at any time during the countdown that this temperature with wind combination occurs that there will be a concern as to how long it will continue to occur. Realizing this limitation, the statistics for this STS operating constraint are still considered to be useful for the management decision process to judge the magnitude of the problem in a relative probabilistic sense.

2.1 The Statistical Analysis:
The statistical analysis for the ET chill constraint is presented under four topical questions for KSC.

2.1.1 What are the chances (percent risk) that the ET chill constraint will occur: (a) On the hour? (Table 1). Example Figure 3. (b) At least one time in 9 consecutive hours? (Table 2). Example Figure 4. (c) At least two times in 9 consecutive hours? (Table 3). Example Figure 5. From Tables 1, 2, and 3 it is seen that the only months at KSC that there is a concern for the occurrence of the ET chill constraint are November through April. All references to time of day is Local Standard Time (LST) which is for KSC Eastern Standard Time.

During February there is a 5.8 percent chance that the ET chill constraint will occur at 0500 hours (Table 1). During February (Table 2) there is a 14.4 percent chance that the ET chill constraint will occur at least one time during the 9 hours exposure ending at 0500 hours. During February (Table 3) there is a 7.8 percent chance that the ET chill constraint will occur at least two times during the 9 hours exposure ending at 0500 hours.

The most significant points in this analysis are that the ET chill constraint occurs most frequently during the early morning hours during the winter months (Tables 1, 2 and 3) and that this is the time of day during the winter months that the ground wind launch constraint (Table 4) is less frequent. (See Figures 3, 4 and 5 for comparisons). If it is assumed that the occurrence of the ET chill constraint at least two times during 9 hours exposure (Table 3) is most representative of the real constraint, then there is from 6 to 10 percent chance for a launch delay for the hours from 2300 to 1400 (LST) during January and February. The basis for this conclusion is that the launch commit criteria, as written, states that "the countdown shall not be continued nor the Shuttle launched" if this combination for ambient

temperature and wind exists for more than 30 minutes. There is no provision in the criteria to resume the countdown. Hence, it may be assumed that when this constraint occurs during the countdown that day is a NO-GO launch day.

2.1.2 What are the chances (percent risk) that the ground wind launch constraint will occur on the hour? (Table 4). During February, the best time of day (Table 4) for launch to minimize the chances for a launch delay due to the ground wind launch constraint is 0600 to 0700 hours. Reference is made to two previous memoranda which presents a detailed statistical analysis for this constraint. They are: (1) MSFC memorandum ED44-(64-88) "STS FRF, Lift-Off and RTLS Runway Constraint Statistics For KSC," dated July 14, 1988, and
(2) MSFC memorandum ED44-(107-88), "Lift-Off and RTLS Runway Wind Statistics for NSTS Launch Sensitive Studies," dated August 31, 1988.

2.1.3 What are the chances (percent risk) that either the ET chill constraint or the ground wind launch constraint will occur: (a) on the hour? (Table 5) Example Figure 3. (b) ET chill at least one time in 9 hours exposure or the ground wind constraint on the 9th hour? (Table 6) Example Figure 4. (c) ET chill at least two times in 9 hours exposure or the ground wind constraint on the 9th hour? (Table 7) Example Figure 5.

From Table 5 during February there is a 25.9 percent chance at 0500 hours that either the ET chill constraint will occur on the hour or the ground wind launch constraint. If the probabilities for the ET chill constraint on the hour, Table 1, are added to the ground wind launch constraint probabilities, Table 4, then this sum is only 1 or 2 percentage point greater than the combined probabilities given in Table 4. This indicates that these statistics are almost mutually exclusive. The probabilities for the ET chill constraint for the 9 hour exposure period and the ground wind launch constraint on the 9th hour are not mutually exclusive.

From Table 6, during February there is a 32.9 percent chance at 0500 hours that either the ET chill constraint will occur at least one time in 9 hours exposure or the ground wind launch constraint will occur on the 9th hour. From Table 7, this percent chance is 28.0 at 0500 hours during February for the occurrence of the ET chill constraint at least two times in 9 hours exposure. It is suggested that Table 7

gives realistic statistics for the launch delay risk due to the combined ET chill constraint with the launch ground wind. From Figure 5 it is seen that the best time of day during February for launch due to the combined constraints is 1900 hours. The impact of the ET chill constraint for the hours 2200 to 0700 is clearly noted.

2.1.4 What are the chances (percent risk) that the ET chill constraint will become unfavorable (NO-GO) during 8 hours following a favorable (GO) condition at the start hour: (a) At least one time in 8 hours exposure? (Table 8, see example Figure 6) (b) At least two times in 8 hours exposure? (Table 9, see example Figure 6)

For this analysis let's assume that the ET cryogenic loading will begin only if the ambient temperature with wind conditions are favorable. The chances that these conditions are unfavorable at the beginning of tanking are given in Table 1. Now the question is: What are the chances for a countdown termination (see paragraph 1.1) during the following 8 hours? For example, during February, given that tanking begins at 0000 hours under a favorable condition (GO) for an 0800 hour launch then there is a 7.1 percent chance (Table 8 or Figure 6) that an unfavorable (NO-GO) condition will occur at least one time by 0800 hours. For the same example there is a 3.2 percent chance that an unfavorable condition will occur at least two times (Table 9, Figure 6).

To use this additional information as a conditional probability prediction model to an advantage on the DOL an evaluation for the ET chill constraint is required prior to cryogenic loading. A time conditional probability prediction model for various initial conditions and exposure periods could be established.

2.2 Other Launch Commit Ambient Temperature Restrictions: Reference is made to JSC 1600 Section 1.4.1.A, to the 24 hour average temperature requirement ≤ 41 deg F preceding the ET propellant loading. Using 29 years of hourly ambient temperature records for KSC, the average temperature for each day was computed. The percentage of days that had a daily average temperature ≤ 41 deg F by monthly reference periods is given in the following Table (A).

Table A. The percentage of days by monthly reference periods that had a daily average ambient temperature $\leq$ 41 deg F at KSC.

Month	January	February	March	April...November		December
Percent	3.00	0.73	0.11	0.00	0.00	1.11

Reference is made to JSC 1600 section 1.4.1 B (1) constraint for ambient temperature exceeding 99 deg F. The available 29 years of daily maximum temperate data for KSC does not contain a temperature $\geq$ 99 deg F. The probability for the occurrence of a daily maximum temperature $\geq$ 99 deg F for KSC can only be derived from a probability model.

The probability of occurrence for the above two launch commit constraints are considered to be so rare as to have no significant impact on the statistical analysis for launch delay. However, these constraints should be monitored on the DOL.

The technical material presented in this memorandum was prepared with the assistance of O. E. Smith and W. Batts (CSC/ATD, Special Projects, Huntsville, Alabama) under contract NAS8-37708.

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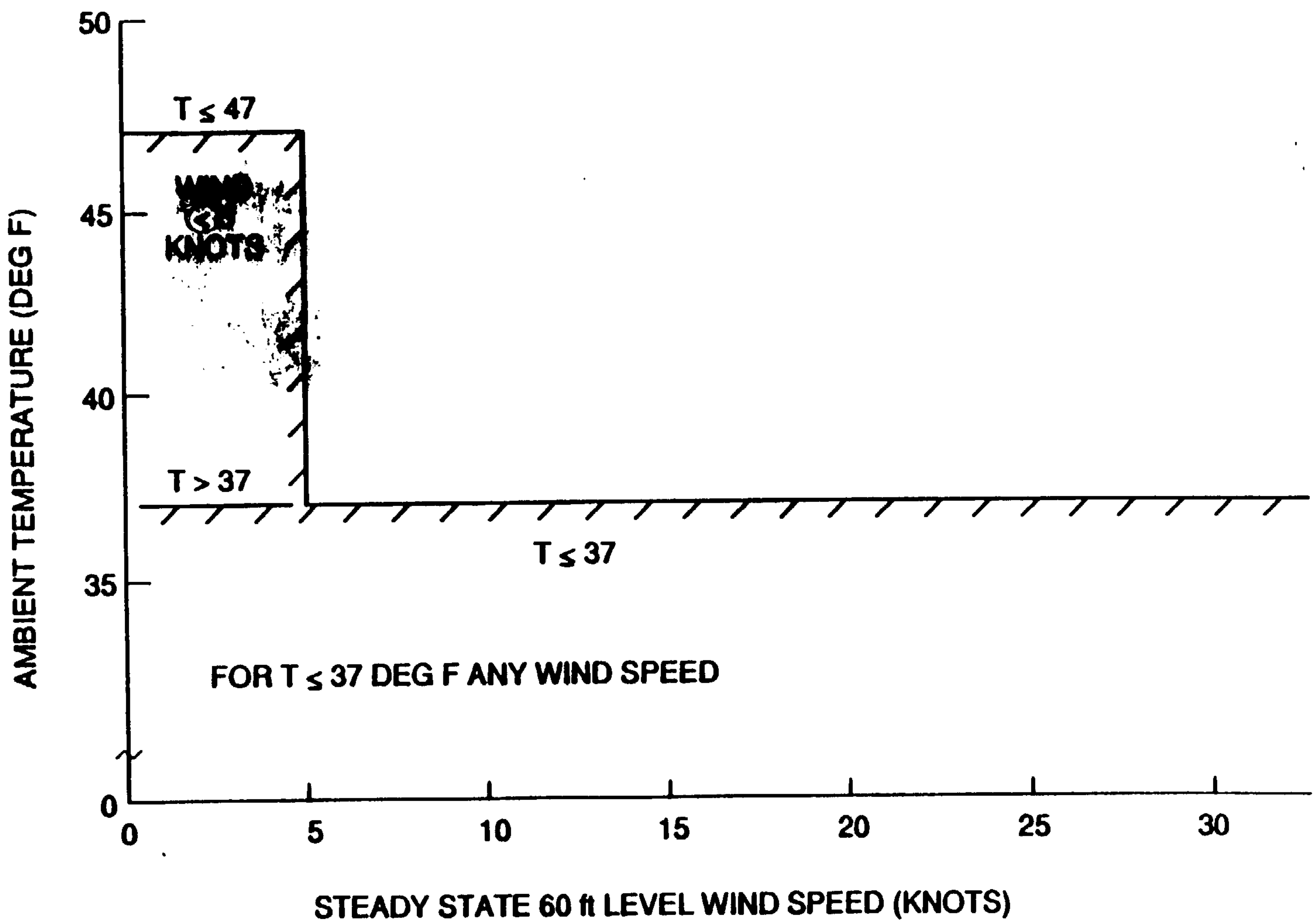

FIGURE 1. AMBIENT TEMPERATURE WITH WIND CONSTRAINT FROM START OF ET CRYOGENIC LOADING FOR ET CHILL EFFECTS ON SRB.

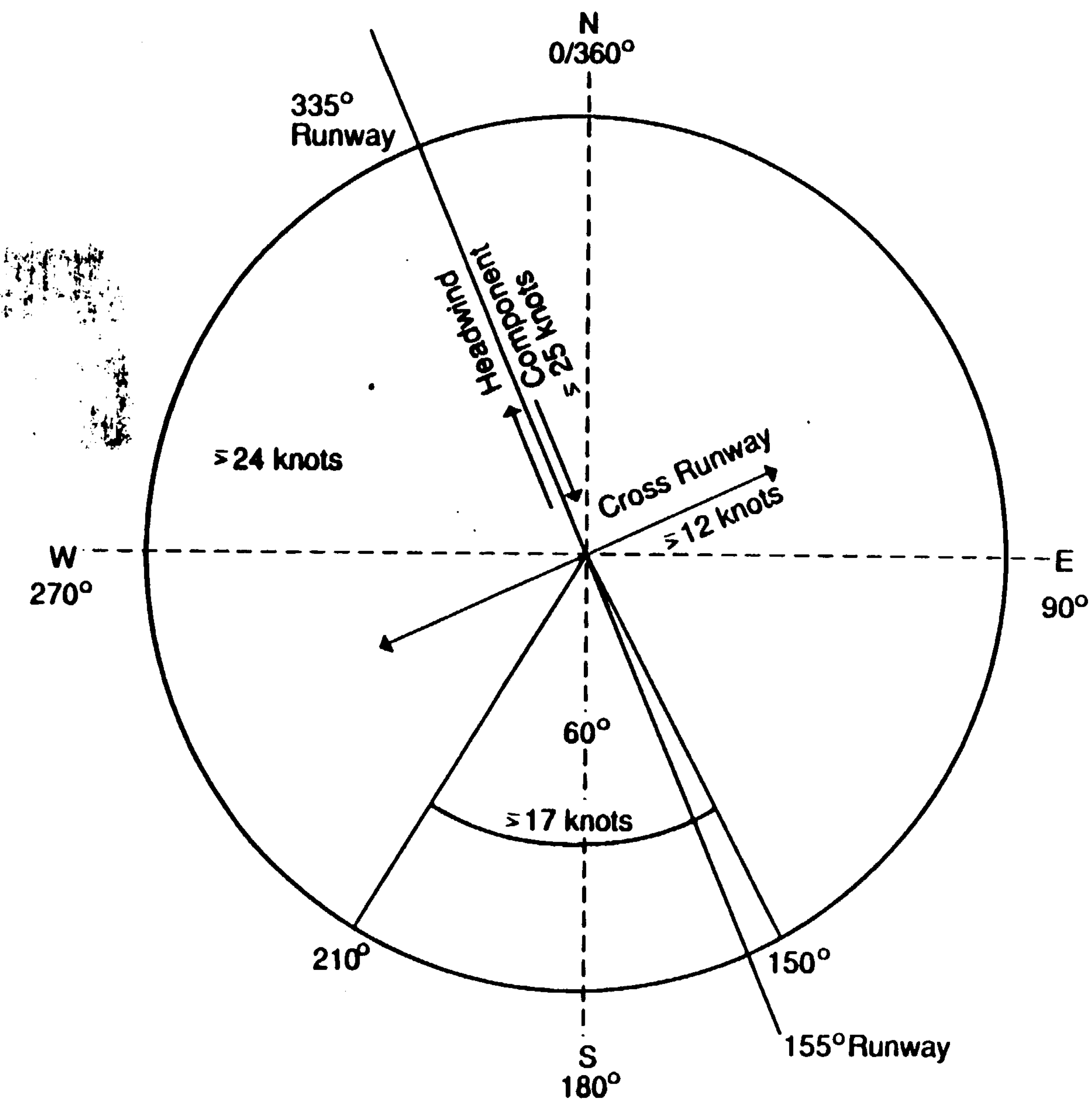

FIGURE 2. CURRENT STS LIFT-OFF AND RTLS RUNWAY WIND CONSTRAINTS

5 4675 8 60

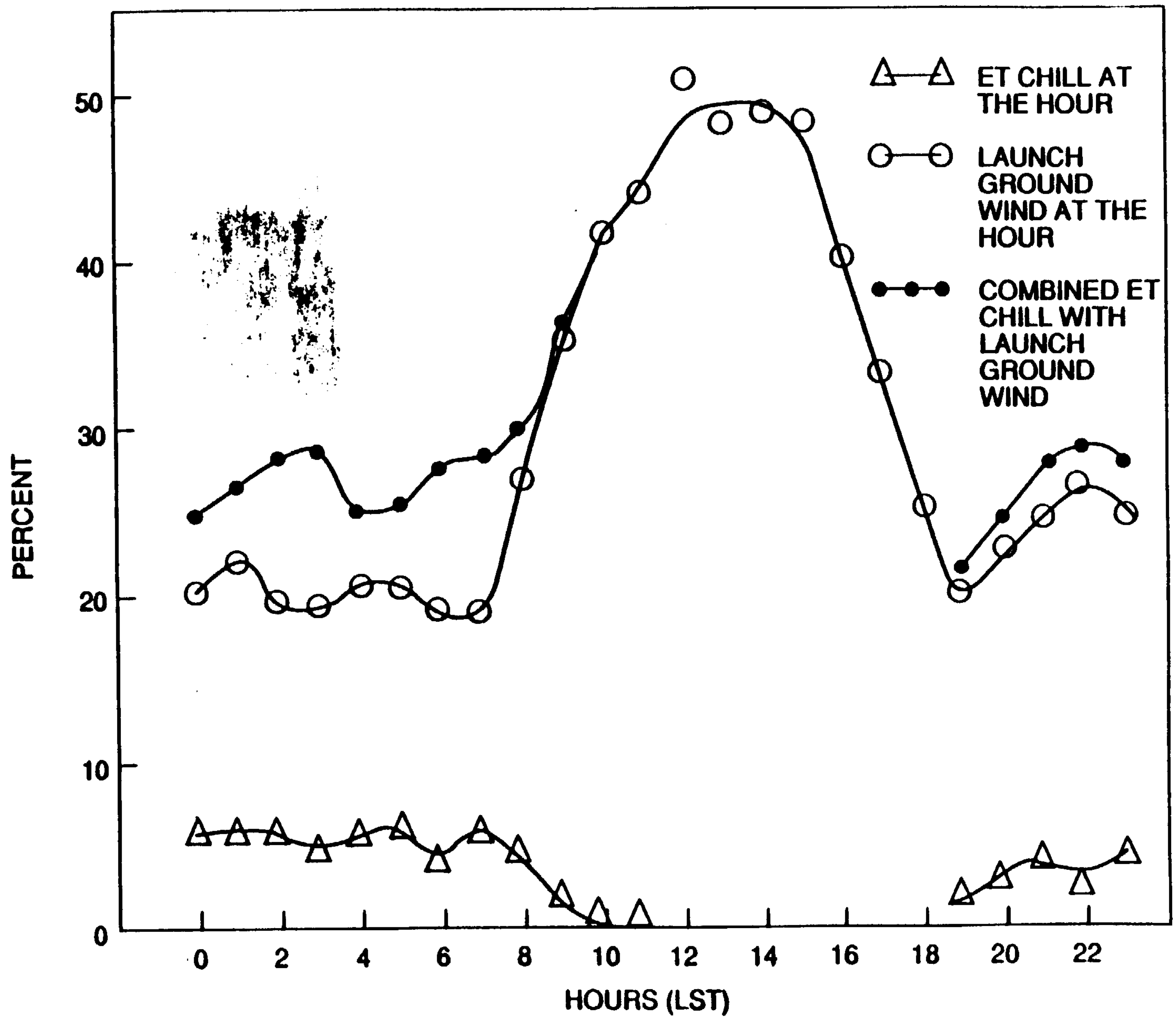

FIGURE 3. PROBABILITY COMPARISONS FOR ET CHILL CONSTRAINT ON THE HOUR WITH GROUND WIND LAUNCH CONSTRAINT,

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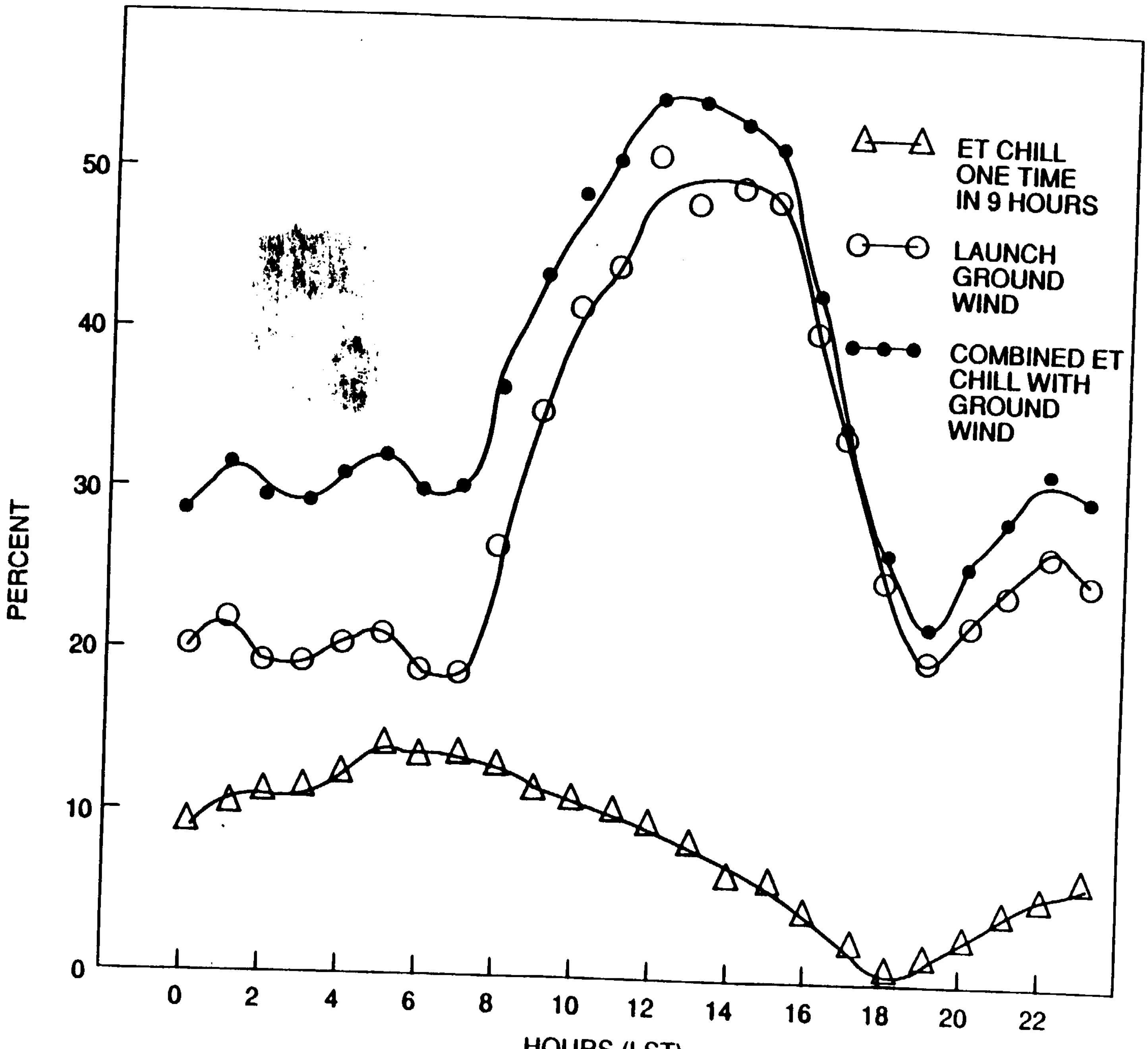

FIGURE 4. PROBABILITY COMPARISONS FOR ET CHILL CONSTRAINT AT LEAST ONE TIME IN NINE HOURS WITH GROUND WIND LAUNCH CONSTRAINT, FEBRUARY, KSC.

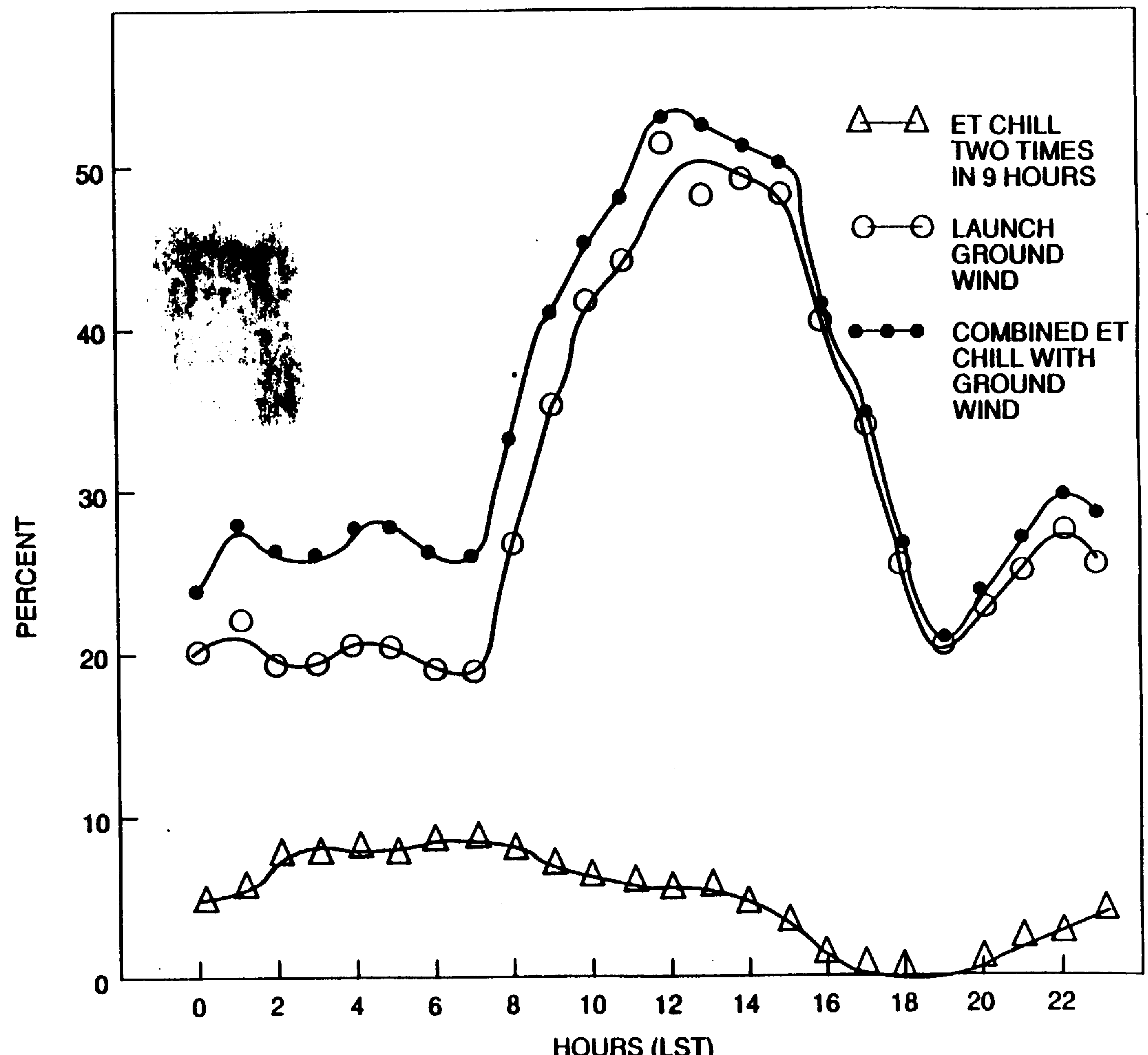

FIGURE 5. PROBABILITY COMPARISONS FOR ET CHILL CONSTRAINT AT LEAST TWO TIMES IN NINE HOURS WITH GROUND WIND LAUNCH

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MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	4.8	[illegible]	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.4
1	6.6	6.1	1.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	3.5
2	6.3	6.1	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.6
3	5.8	4.3	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.2
4	5.5	5.3	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	3.7
5	6.9	5.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.6
6	7.6	4.8	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.6
7	7.1	5.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.6
8	5.1	4.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.4
9	2.5	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
10	1.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
11	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
12	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.4
19	3.2	1.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.5
20	4.1	2.5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	5.3
21	4.6	3.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	6.0
22	5.1	2.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	5.5
23	5.1	4.1	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.7

TABLE 1. PERCENT RISK FOR ET CHILL CONSTRAINT ON THE HOUR (LST), KSC

5-4680-8-58

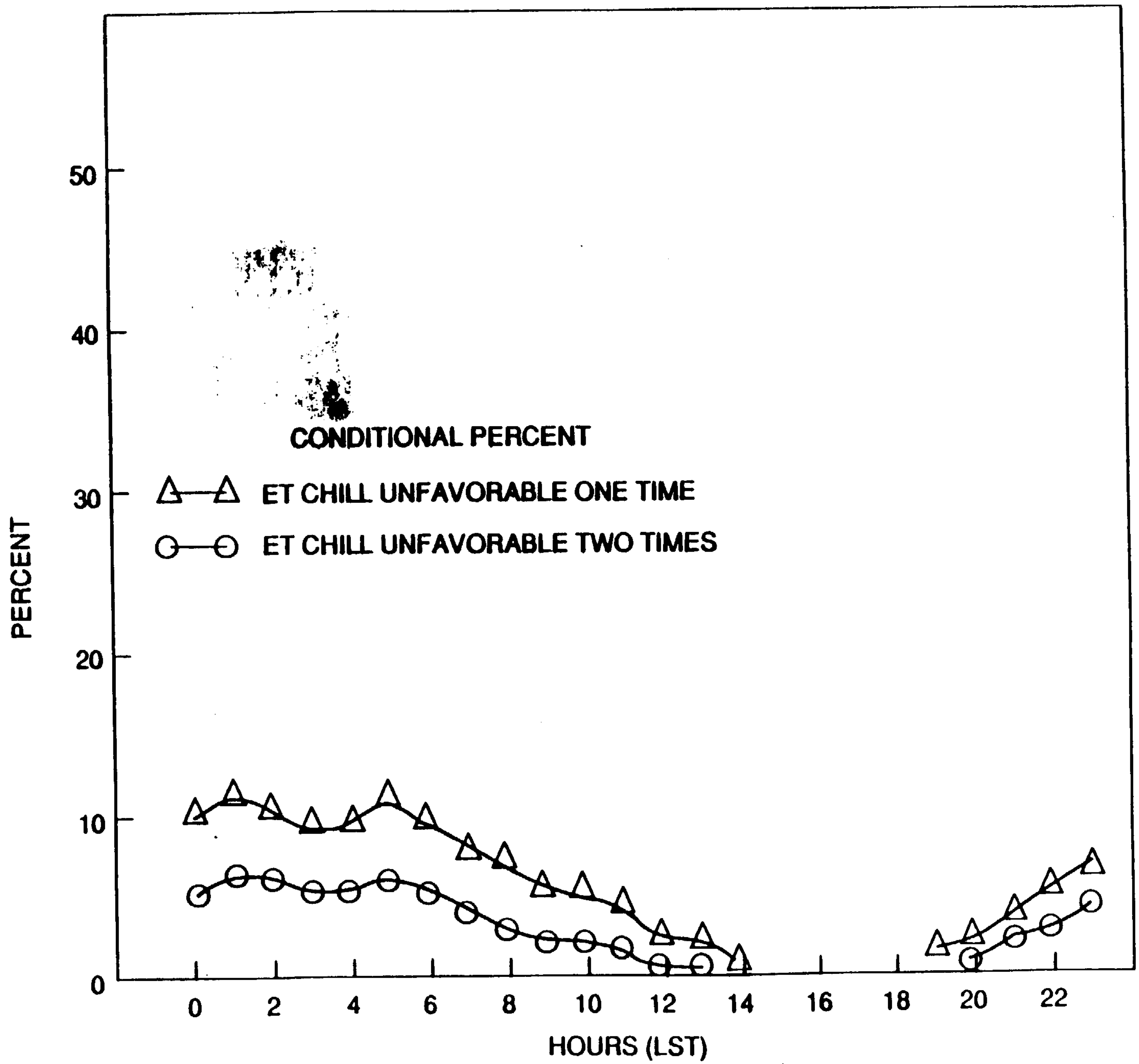

FIGURE 6. CONDITIONAL PROBABILITY FOR ET CHILL CONSTRAINT AT LEAST ONE AND TWO TIMES NO-GO IN EIGHT HOURS

ORIGINAL PAGE IS OF POOR QUALITY

PERCENTAGE OF BADS AFTER START TIME DURATION 9 HRS GIVEN A FAVORABLE START OR UNFAVORABLE START
AT LEAST 1 BADS DURING TIME DURATION

TANKING ET-CHILL CONSTRAINTS ONLY
[illegible] DATA BASE 1957-1970

MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	8.5	9.9	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	9.3
1	9.9	10.6	2.8	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.1	9.7
2	10.9	11.4	2.8	0.2	0.2	0.0	0.0	0.0	0.0	0.0	2.1	10.6
3	12.0	11.6	3.2	0.5	0.2	0.0	0.0	0.0	0.0	0.0	2.1	11.3
4	12.2	12.9	3.7	0.5	0.2	0.0	0.0	0.0	0.0	0.0	2.1	11.3
5	12.7	14.4	3.9	0.5	0.2	0.0	0.0	0.0	0.0	0.0	1.9	11.1
6	13.1	13.7	4.4	0.7	0.2	0.0	0.0	0.0	0.0	0.0	1.9	11.1
7	12.7	13.9	4.8	0.7	0.2	0.0	0.0	0.0	0.0	0.0	2.1	10.2
8	11.8	13.2	4.4	0.7	0.2	0.0	0.0	0.0	0.0	0.0	1.4	10.0
9	11.3	11.9	3.9	0.7	0.2	0.0	0.0	0.0	0.0	0.0	1.2	10.0
10	10.4	11.1	3.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.2	9.5
11	10.1	10.4	3.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.2	8.8
12	9.7	9.9	3.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.2	8.1
13	9.2	8.1	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.9
14	8.3	6.8	2.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	7.4
15	7.6	6.3	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	6.5
16	5.1	4.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.4
17	2.5	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
18	2.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.6
19	3.5	1.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.7
20	4.6	3.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	5.5
21	5.8	4.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	7.2
22	6.9	5.1	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	7.9
23	7.8	6.6	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	8.5

TABLE 2. PERCENT RISK FOR ET CHILL CONSTRAINT AT LEAST ONE TIME IN 9 HOURS EXPOSURE, KSC

5-4681-8-58

ORIGINAL PAGE IS OF POOR QUALITY

PERCENTAGE OF BADS AFTER START TIME DURATION 9 HRS GIVEN A FAVORABLE START OR UNFAVORABLE START
AT LEAST 2 BADS DURING TIME DURATION

TAN[illegible]TRAINTS ONLY
[illegible] BASE 1957-1970

HR	1	[illegible]	3	4	5	6	7	8	9	10	11	12
	MONTHS											
0	6.5	[illegible]	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	7.0
1	6.7	[illegible]	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	7.2
2	7.4	7.6	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	8.1
3	8.3	7.8	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	8.6
4	9.2	8.1	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	8.3
5	9.4	7.8	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	7.9
6	9.9	8.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	6.3
7	10.1	8.6	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	7.2
8	9.9	7.8	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	7.6
9	9.7	7.3	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	6.0
10	9.4	6.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	6.0
11	8.8	6.3	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	6.0
12	8.1	5.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	6.0
13	7.6	5.6	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.3
14	7.4	4.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.4
15	4.6	3.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.5
16	2.5	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
17	1.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
18	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
19	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2
20	3.0	1.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.5
21	3.9	2.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.8
22	4.6	2.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	6.5
23	5.3	4.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	6.7

TABLE 3. PERCENT RISK FOR ET CHILL CONSTRAINT AT LEAST TWO TIMES IN 9 HOURS EXPOSURE, KSC

5-4682-8-58

PERCENTAGE OF BADS AFTER START TIME DURATION 1 HRS GIVEN A FAVORABLE START OR UNFAVORABLE START
AT LEAST 1 BADS DURING TIME DURATION

LAUNCH [illegible] CONSTRAINTS ONLY
[illegible] BASE 1957-1970

MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	17.9	20.4	24.5	23.0	15.8	11.4	5.5	3.7	18.7	26.5	19.9	17.9
1	18.8	22.5	21.1	22.2	13.1	11.0	3.6	3.4	17.2	28.1	18.9	16.0
2	19.1	18.7	19.6	17.7	13.0	12.3	3.6	3.4	17.7	26.0	16.8	14.8
3	16.8	19.8	20.7	18.8	9.5	10.3	4.9	1.7	16.9	24.5	17.3	14.7
4	18.8	21.0	20.0	16.8	10.9	11.4	3.7	1.7	16.1	24.3	15.9	14.6
5	17.1	20.9	19.2	14.8	11.5	7.8	3.0	2.5	16.4	24.3	18.1	14.4
6	19.1	19.1	18.6	17.1	11.2	8.9	2.6	2.7	16.4	24.1	18.0	14.2
7	17.8	19.3	22.2	22.3	19.3	15.5	8.3	7.3	16.6	24.1	18.8	14.8
8	19.2	27.3	33.6	31.8	26.2	22.6	15.7	12.4	23.1	30.5	23.1	17.7
9	27.8	35.7	41.2	38.4	33.5	25.2	19.8	15.5	28.2	36.7	29.6	26.1
10	37.2	42.2	46.5	44.7	35.7	28.1	19.1	14.8	31.4	41.2	35.6	33.6
11	41.0	44.5	48.1	47.7	40.8	30.5	22.2	18.2	36.8	45.9	39.3	41.3
12	43.3	51.3	48.6	46.9	43.3	38.8	26.3	22.6	41.0	46.0	38.9	39.4
13	44.0	48.5	48.6	53.3	45.6	40.3	23.7	27.0	43.3	48.3	39.0	39.8
14	40.9	49.4	50.2	53.3	47.2	44.3	33.0	30.0	44.8	46.9	38.9	35.1
15	39.3	48.7	54.1	52.9	50.0	44.8	32.5	31.4	44.6	46.3	37.2	35.6
16	36.0	40.8	45.9	44.3	44.7	43.6	30.4	28.1	39.9	42.2	28.3	26.9
17	24.8	34.2	38.5	35.7	33.3	31.8	25.9	22.8	30.4	34.8	23.2	18.3
18	20.4	25.9	30.1	29.2	25.3	22.2	22.9	15.5	24.3	28.6	18.6	12.6
19	18.6	20.9	24.6	25.0	17.1	20.3	11.8	10.3	24.3	29.9	15.7	16.5
20	20.0	23.4	24.8	24.9	20.2	16.2	10.2	9.1	24.4	30.2	18.2	17.1
21	21.3	25.4	26.1	24.9	21.3	13.9	6.6	6.2	25.7	29.7	17.5	18.0
22	20.0	27.7	29.4	24.0	19.8	12.4	4.7	5.7	21.5	30.5	20.1	17.1
23	18.4	25.4	24.8	25.4	20.5	11.1	5.3	5.3	18.6	29.8	21.5	18.0

TABLE 4. PERCENT RISK FOR THE GROUND WIND (EITHER LIFT-OFF OR RTLS RUNWAY) CONSTRAINT VERSUS HOUR (LST), KSC

5-4683-8-58

PERCENTAGE OF BADS AFTER START TIME DURATION 1 HRS GIVEN A FAVORABLE START OR UNFAVORABLE START
AT LEAST 1 BADS DURING TIME DURATION

COM[illegible] AND LAUNCH WINDS CONSTRAINTS
[illegible] DATA BASE 1957-1970

MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	[illegible]	[illegible]	26.2	23.1	15.8	11.4	5.5	3.7	18.7	26.5	20.4	22.4
1	[illegible]	[illegible]	22.5	22.2	13.4	11.1	3.6	3.4	17.2	28.2	19.2	19.4
2	24.1	23.8	20.3	18.0	13.0	12.3	3.6	3.4	17.8	26.1	17.1	19.6
3	22.1	23.7	22.1	16.9	9.6	10.3	4.9	1.7	16.9	24.5	17.6	18.9
4	23.8	26.2	21.2	16.9	10.9	11.4	3.7	1.7	16.1	24.4	16.4	18.0
5	23.7	25.9	20.5	14.8	11.6	7.8	3.0	2.5	16.4	24.4	18.4	18.7
6	26.4	23.3	19.4	17.1	11.2	8.9	2.6	2.7	16.4	24.2	18.3	18.8
7	24.2	23.7	23.6	22.4	19.4	15.6	8.4	7.3	16.7	24.2	19.6	20.0
8	23.9	30.4	33.9	31.9	26.2	22.7	15.7	12.4	23.2	30.5	23.4	21.6
9	29.9	36.6	41.3	38.5	33.6	25.2	19.9	15.5	28.2	36.8	29.7	26.9
10	38.4	42.6	46.6	44.8	36.8	28.1	19.2	14.9	31.5	41.3	35.6	34.1
11	42.0	44.6	48.3	47.8	40.9	30.6	22.2	18.3	36.8	46.0	39.4	41.6
12	43.4	51.4	48.7	47.0	43.4	38.9	26.3	22.6	41.1	46.1	39.0	39.4
13	44.1	48.6	48.7	53.5	45.7	40.4	23.8	27.1	43.4	48.4	39.1	39.9
14	41.0	49.5	50.3	53.5	47.3	44.4	33.1	30.1	44.9	47.0	39.0	35.1
15	39.4	48.9	54.3	53.0	50.1	44.9	32.6	31.5	44.7	46.4	37.3	35.6
16	36.1	40.9	46.0	44.4	44.8	43.7	30.5	28.2	40.0	42.3	28.4	26.9
17	24.9	34.3	38.6	35.8	33.3	31.9	25.9	22.9	30.5	34.9	23.2	18.3
18	21.6	28.0	30.2	29.2	25.4	22.2	22.9	15.6	24.4	28.7	18.6	14.0
19	21.9	22.5	25.1	25.1	17.1	20.3	11.8	10.3	24.3	30.0	15.7	19.5
20	24.1	25.5	26.5	25.0	20.2	16.2	10.2	9.2	24.5	30.2	18.4	22.1
21	25.4	28.8	27.4	24.9	21.3	13.9	6.6	6.2	25.7	29.7	18.6	23.5
22	24.7	29.8	31.1	24.0	19.7	12.4	4.7	5.8	21.6	30.6	21.4	22.0
23	23.3	28.9	26.5	25.5	20.6	11.1	5.3	5.3	18.7	29.9	22.8	21.8

TABLE 5. PERCENT RISK FOR THE OCCURRENCE OF EITHER THE ET CHILL CONSTRAINT ON THE HOUR OR THE GROUND WIND LAUNCH CONSTRAINT, KSC

5-4684-8-58

PERCENTAGE OF BADS AFTER START TIME DURATION 9 HRS GIVEN A FAVORABLE START OR UNFAVORABLE START AT LEAST 1 BADS DURING TIME DURATION

COMBINED [illegible] AND LAUNCH WINDS CONSTRAINTS
[illegible] DATA BASE 1957-1970

MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	26.5	[illegible]	27.2	23.1	15.8	11.4	5.5	3.7	18.7	26.5	21.9	27.6
1	27.8	[illegible]	23.9	22.2	13.4	11.1	3.6	3.4	17.2	28.2	20.9	26.1
2	27.8	30.3	22.2	18.0	13.2	12.3	3.6	3.4	17.8	26.1	18.8	25.4
3	27.6	29.9	23.8	17.1	9.8	10.3	4.9	1.7	16.9	24.5	19.3	26.2
4	30.4	31.7	23.5	17.1	11.2	11.4	3.7	1.7	16.1	24.4	17.8	25.0
5	28.6	32.9	22.8	16.1	11.8	7.8	3.0	2.5	16.4	24.4	19.8	24.7
6	31.1	30.9	22.5	17.1	11.4	8.9	2.6	2.7	16.4	24.2	19.7	24.5
7	29.6	30.9	26.7	22.6	19.6	15.6	8.4	7.3	16.7	24.2	20.8	23.6
8	29.1	37.6	37.4	31.9	26.5	22.7	15.7	12.4	23.2	30.5	24.4	26.5
9	36.9	44.2	44.1	38.8	33.8	25.2	19.9	15.5	28.2	36.8	30.6	34.0
10	45.1	49.2	49.4	45.1	35.8	28.1	19.2	14.9	31.5	41.3	36.4	40.7
11	48.3	51.3	51.5	47.8	40.9	30.6	22.2	18.3	36.8	46.0	39.9	47.0
12	49.9	57.0	50.6	47.0	43.4	38.9	26.3	22.6	41.1	46.1	39.7	45.2
13	50.6	54.7	50.6	53.5	45.7	40.4	23.8	27.1	43.4	48.4	39.8	45.0
14	46.5	53.6	51.5	53.5	47.3	44.4	33.1	30.1	44.9	47.0	39.7	40.2
15	44.7	52.7	55.7	53.0	50.1	44.9	32.6	31.5	44.7	46.4	38.0	40.0
16	39.4	43.1	46.2	44.4	44.8	43.7	30.5	28.2	40.0	42.3	28.6	30.3
17	27.0	34.8	38.8	35.8	33.3	31.9	25.9	22.9	30.5	34.9	23.2	19.3
18	22.5	26.7	30.2	29.2	25.4	22.2	22.9	15.6	24.4	28.7	18.6	14.2
19	21.9	22.5	25.1	25.1	17.1	20.3	11.8	10.3	24.3	30.0	15.7	19.8
20	24.5	26.0	26.5	26.0	20.2	16.2	10.2	9.2	24.5	30.2	18.4	22.1
21	26.5	29.3	27.8	24.9	21.3	13.9	6.6	6.2	25.7	29.7	18.8	24.9
22	26.1	32.1	31.4	24.0	19.7	12.4	4.7	5.8	21.6	30.6	21.8	24.1
23	25.2	30.9	27.0	25.5	20.6	11.1	5.3	5.3	18.7	29.9	23.5	26.5

TABLE 6. PERCENT RISK FOR THE OCCURRENCE OF EITHER THE ET CHILL CONSTRAINT AT LEAST ONE TIME IN 9 HOURS OR THE GROUND WIND LAUNCH CONSTRAINT, KSC

5-4685-8-58

PERCENTAGE OF BADS AFTER START TIME DURATION 9 HRS GIVEN A FAVORABLE START OR UNFAVORABLE START
AT LEAST 2 BADS DURING TIME DURATION

COM[illegible] AND LAUNCH WINDS CONSTRAINTS
[illegible] BASE 1957-1970

MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	22.9	[illegible]	26.9	23.1	15.8	11.4	5.5	3.7	18.7	26.5	21.4	25.2
1	24.6	[illegible]	23.5	22.2	13.2	11.1	3.6	3.4	17.2	28.2	20.4	23.4
2	24.8	26.9	22.0	17.8	13.0	12.3	3.6	3.4	17.8	26.1	18.3	22.7
3	24.2	26.5	23.3	16.9	9.6	10.3	4.9	1.7	16.9	24.5	18.8	23.5
4	27.6	28.1	22.8	16.9	10.9	11.4	3.7	1.7	16.1	24.4	17.3	22.4
5	26.1	28.0	22.1	14.8	11.6	7.8	3.0	2.5	16.4	24.4	19.6	21.8
6	28.5	26.6	21.5	17.1	11.2	8.9	2.6	2.7	16.4	24.2	19.2	20.2
7	27.8	26.5	24.8	22.4	19.4	15.6	8.4	7.3	16.7	24.2	19.4	21.0
8	27.7	33.8	35.8	31.9	26.2	22.7	15.7	12.4	23.2	30.5	23.6	24.6
9	35.5	40.9	42.9	38.5	33.6	25.2	19.9	15.5	28.2	36.8	30.1	30.9
10	44.2	45.9	48.3	44.8	35.8	28.1	19.2	14.9	31.5	41.3	36.1	38.3
11	47.3	48.5	49.7	47.8	40.9	30.6	22.2	18.3	36.8	46.0	39.6	45.1
12	48.5	54.7	49.7	47.0	43.4	38.9	26.3	22.6	41.1	46.1	39.2	43.6
13	49.0	52.2	49.7	53.5	45.7	40.4	23.8	27.1	43.4	48.4	39.6	43.2
14	46.1	51.5	50.8	53.5	47.3	44.4	33.1	30.1	44.9	47.0	39.5	38.8
15	42.4	50.4	54.5	53.0	50.1	44.9	32.6	31.5	44.7	46.4	37.6	38.3
16	37.7	41.4	46.0	44.4	44.8	43.7	30.5	28.2	40.0	42.3	28.4	27.5
17	26.5	34.5	38.6	35.8	33.3	31.9	25.9	22.9	30.5	34.9	23.2	18.8
18	21.6	26.2	30.2	29.2	25.4	22.2	22.9	15.6	24.4	28.7	18.6	12.8
19	20.3	21.0	24.7	25.1	17.1	20.3	11.8	10.3	24.3	30.0	15.7	17.6
20	23.1	24.2	25.3	25.0	20.2	18.2	10.2	9.2	24.5	30.2	18.2	20.4
21	25.1	27.5	27.4	24.9	21.3	13.9	6.6	6.2	25.7	29.7	17.8	22.5
22	24.5	30.3	30.9	24.0	19.7	12.4	4.7	5.8	21.6	30.6	21.1	22.7
23	23.6	29.1	26.2	25.5	20.6	11.1	5.3	5.3	18.7	29.9	22.8	24.6

TABLE 7. PERCENT RISK FOR THE OCCURRENCE OF EITHER THE ET CHILL CONSTRAINT AT LEAST TWO TIMES IN 9 HOURS OR THE GROUND WIND LAUNCH CONSTRAINT, KSC

5-4686-8-58

ORIGINAL PAGE IS
OF POOR QUALITY

PERCENTAGE OF BADS AFTER START TIME DURATION 8 HRS GIVEN A FAVORABLE START
AT LEAST 1 BADS DURING TIME DURATION

TANKING ET CHILL CONSTRAINTS ONLY
[illegible] A BASE 1957-1970

MONTHS

HR	1	[illegible]	3	4	5	6	7	8	9	10	11	12
0	9.8	[illegible]	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	9.7
1	9.6	11.2	2.8	0.0	0.2	0.0	0.0	0.0	0.0	0.0	1.9	8.6
2	8.0	10.4	2.3	0.2	0.2	0.0	0.0	0.0	0.0	0.0	1.9	7.5
3	8.3	9.5	1.6	0.5	0.2	0.0	0.0	0.0	0.0	0.0	1.4	6.3
4	7.6	9.6	2.3	0.5	0.2	0.0	0.0	0.0	0.0	0.0	1.0	4.3
5	7.7	11.8	2.3	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.5	5.1
6	8.0	9.8	2.1	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.2	5.6
7	7.4	7.8	2.8	0.7	0.2	0.0	0.0	0.0	0.0	0.0	1.0	5.4
8	6.1	7.1	2.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.0	6.8
9	5.2	6.2	3.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.9
10	4.5	6.1	2.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.7
11	4.2	4.6	1.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	4.4
12	2.3	2.3	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	3.2
13	0.7	2.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.8
14	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2
19	3.1	1.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.8
20	4.6	3.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	5.9
21	5.8	4.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	7.6
22	7.3	5.2	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	8.3
23	8.0	6.9	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	8.9

TABLE 8. CONDITIONAL PROBABILITY – PERCENT CHANCE THAT THE ET CHILL CONSTRAINT WILL BECOME UNFAVORABLE (NO-GO) AT LEAST ONE TIME IN 8 HOURS GIVEN A FAVORABLE CONDITION (GO) AT THE START HOUR, KSC

5-4687-8-58

PERCENTAGE OF BADS AFTER START TIME DURATION 8 HRS GIVEN A FAVORABLE START
AT LEAST 2 BADS DURING TIME DURATION

TA[illegible]STRAINTS ONLY
[illegible]A BASE 1957-1970

MONTHS

HR	1	2	3	4	5	6	7	8	9	10	11	12
0	[illegible]	6.1	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	7.3
1	5.6	6.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	6.0
2	4.4	6.4	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	4.9
3	4.6	5.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.9
4	5.1	5.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.6
5	5.0	6.5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.4
6	5.5	5.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4
7	5.5	4.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
8	5.3	3.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.1
9	4.5	2.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.1
10	3.5	2.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.6
11	3.0	2.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.6
12	1.6	1.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2
13	0.5	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2
20	2.9	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.7
21	3.9	2.4	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.2
22	4.9	2.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	6.8
23	5.8	4.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	7.0

TABLE 9. CONDITIONAL PROBABILITY – PERCENT CHANCE THAT THE ET CHILL CONSTRAINT WILL BECOME UNFAVORABLE (NO-GO) AT LEAST TWO TIMES IN 8 HOURS GIVEN A FAVORABLE CONDITION (GO) AT THE START HOUR, KSC

5-4688-8-58

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APPENDIX IV B

AN EXECUTIVE SUMMARY ON THE DETERMINATION OF EXPECTATIONS FOR FUTURE EVENTS

EXECUTIVE SUMMARY

1. ASSURANCE: THE UNDERSTANDING DEVELOPED FROM PREVIOUS EXPERIENCE WHICH DETERMINES THE EXPECTATIONS FOR FUTURE EVENTS
2. QUALITY OR ASSURANCE
3. QE: QUANTIFIED EXPECTATIONS FOR IMPROVED PERFORMANCE

BY: ADVANCED RESEARCH TECHNOLOGY SYSTEMS, INC. 10/88

HUNSUCKER 6 DEC 88

1. ASSURANCE...

This manual is mostly a sales pitch for a technique identified as Mission Assurance Probability (MAP) developed by Roland P. Swank. The basis of MAP is to take a holistic approach to assurance. In Swank's words, "The philosophy of the MAP is to provide the decision-makers with a quantitative understanding of the contributions or effects of all involved considerations, putting them in the best position possible for making the decisions necessary to achieve the desired results. These quantifications are in the form of the probability or assurance of achieving the defined objective and they directly relate with all of those considerations that a decision-maker must deal with."

Swank includes a listing of projects where the method reportedly saved programs large sums of money. Most of the ones cited are space or defense related. See section 8 in the manual for more details.

While Swank contends that MAP is copyrighted, what is presented in the manual is just a systematic approach to quality assurance taking an approach which relates to the whole objective of a program. The major advantages seem to be the systematic formal nature of the approach which leads to the identity of troublesome elements. This in turn gives the program a chance to redesign uncertainties out of the project.

2. QUALITY OR ASSURANCE

This manual is mostly a subset of the previous one. In fact, most of the exact pages are contained in the first.

3. QE...

In this manual, Swank presents somewhat the same material in a different format. Instead of calling the procedure MAP, he refers to it as QE or Quantified Expectations. In this presentation he discusses some of the advantages of quantifying assurance. While still a sales pitch, the part about the advantages of quantifaction is worth a quick read.

DISCUSSION AND SUGGESTIONS:

Perhaps the major advantage of MAP is the formal nature of the approach. It is a well established principle, that the major advantage of systems of this sort is the knowledge gained when the system is analyzed in a formal mode. This allows an understanding of the relationships between many complex elements.

If this system is under review for use with the shuttle program, I would suggest that you get additional information by contacting some of the people who have used the system in the past. Issues such as cost, ease of use, ease of managerial interpretation, and over all applicability could be addressed in this manner.

In my opinion, a system such as this is necessary for the continued evolution of the shuttle program. While this particular system may not be the one, a formal method of quantifying and identifying risk from a holistic sense should be used. While the numbers generated may well be, at best, approximate, at least a formal system will allow for continuity of risk evaluation as the shuttle program goes through numerous changes in its development and operation.

CHAPTER V

THE MANAGEMENT OF CHANGE

V. THE MANAGEMENT OF CHANGE

1.0 INTRODUCTION

The purpose of this chapter is to familiarize NSTS and NASA with the research that has been undergoing dealing with the Management of Change, i.e. Transition Management. As this grant was established as "An Investigation of Transitional Management Problems for the NSTS at NASA" an up-to-date understanding of transition management is necessary for all principals involved in the proposed R&D to Operations shift of NSTS. A fundamental purpose for initiating the transition is to accomplish goals and objectives for the future direction of NSTS. Therefore, organization is needed for the transition due to the fact that NASA may be unable to obtain some of their goals, specifically an increased flight rate, while in its present R&D state. Some of our research has been directly devoted to developing an organized, systematic way, to begin planning the transition management for the NSTS at NASA.

2.0 BACKGROUND

Through the culmination of literature searches, national and international presentations, an industrial interview process, and published papers, a substantial amount of information has been gained and produced on the otherwise

relatively unresearched area of transition management as applied to an R&D to Operations shift. The Appendix to this chapter contains some of the research we have presented and published over the previous year.

Appendix V A consists of one of the papers which is currently undergoing the refereeing process: "Transition Life Cycle--An R&D to Operations Perspective". The major focus of this paper is the Transition Life Cycle model developed by our research team. The Transition Life Cycle contends that there are four phases (cycles) in an organizational transition. Considerations of the theory and issues outlined in this paper should assist NSTS in facilitating the smooth transition management for an R&D to Operations shift.

"Preparing NSTS Managers For An Operational Era", found in Appendix V B.1, is a paper that has been accepted for publication. The paper is aimed at the principles involved in the proposed shift. Appendix V B.2 is an appendix to Appendix V B.1 and lists considerations in the training topics for NSTS personnel.

Appendix V C contains another paper which is currently undergoing the refereeing process: "Transition Management: Planning A Complex R&D to Operations Change". The focus of this paper is on the planning of the initial stages of the transition management. The paper uses a four step analysis in conjunction with the previously discussed transition life cycle model. Furthermore, the paper goes on to suggest the utilization of existing methods for achieving a smooth

transformation under different levels of organizational uncertainties.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The papers listed above, and the information contained in previous papers, presentations, and industrial interviews, are all vital to NSTS in providing current knowledge of transition management activities. It is our belief that the area of concern, the management of change, will, in itself, be continually changing. Therefore, in order to stay on the cutting edge until NSTS has reached its desired shift, i.e. that of moving to an Operational era, more research should be carried out in this area. Specifically, the thought process of sifting through the theory on transition and combining this information with new information discovered in either the literature or through industrial visits needs to be continued. A significant part of this process is the continual revising and refining of the theory into a format acceptable for adaptation by NSTS.

APPENDIX V A

TRANSITION LIFE CYCLE--AN R&D TO OPERATIONS PERSPECTIVE

TRANSITION LIFE CYCLE - AN R&D TO OPERATIONS PERSPECTIVE

INTRODUCTION

Back in 1972, the National Aeronautics and Space Administration (NASA) began the development of a space transportation system that we know today as the Space Shuttle. This vehicle could carry payloads such as Space Station parts, satellites, probes, and people into low Earth orbit for a variety of missions. Beside these important functions, it would also be the world's first reusable spacecraft. Reusability would require the development of technology that was at or above the current technology level in the astronautical field. For example, this criteria would require the development of the largest solid fuel rocket boosters (SRB) ever created; each SRB produces approximately three million pounds of thrust and is completely reusable. Moreover, it would be the first time solid fuel rockets would be used for manned spaceflight.

In 1981, after nine years of research and testing, the Space Shuttle "Columbia" successfully flew the first mission of this new generation of vehicle. During the next twenty five space shuttle flights, the orientation of the entire program was changing, in that most of the initial development of the shuttle had been completed. Now, the focus of the space shuttle program was now towards the establishment of routine and timely operations that would eventually lead to an increased number of flights per year. This would not be an easy task, due to the size and complexity of the

organization, and the difficulties created by the Challenger accident in 1986. Also, while many organizations move a specific product from R&D to production, rarely has the entire organization made this type of movement. In addition, there is no previous experience in routinely flying into space, and there is little existing scholarly work which deals with the transition of an organization from R&D to operations.

Due to these problems, NASA authorized a study to be conducted concerning the transition of an organization, in this case the Space Shuttle program, from essentially an R&D or design environment to that of an operational or production environment. This article outlines some preliminary transition considerations that were developed as an outcome of this research. It is hoped that these considerations will be of service not only to NASA for use with both the shuttle program and the following project of the space station, but will also be useful to other organizations proposing a major transition.

PLANNING THE PROCESS OF CHANGE

The basic purpose of initiating a change program is to accomplish some goal or objective for the future direction of the organization which can not be accomplished in the present system. The introduction of such change usually creates severe disturbances in the dynamics of the present system. Although the changes in the organization may be

necessary, no one will be comfortable with the instability created by it. One consideration in this area is the amount of disturbance that the technical, political, and cultural systems of the organization can bear as the changes affect the organization.

When the dynamics of the system change to the point where a transition to a new system becomes necessary, the consideration of the four questions contained in Table One provides a structure for the development of strategy. These questions, while helping to understand the present system, lend guidance and provide insight into gaining familiarity with the objectives, direction, and the mechanism of the change process.

With Question One, "Where are we now?", the organization needs to assess its current status, strengths, and weaknesses. Questions such as the current composition of the goals, objectives, and value system must be answered. Oftentimes, historic performance data is necessary to address this question; however, in a white collar R&D organization, the quantification of work can be quite difficult. The second question, "Where do we want to be?" is related to the future direction of the organization. Objectives and a method for measuring transition success must be defined to provide a planning target. Obviously, if the new state is to be a truly operational one, the definition of success must include some consideration for timely performance.

1. WHERE ARE WE NOW?
2. WHERE DO WE WANT TO BE?
3. HOW DO WE GET THER?
4. HOW BADLY DO WE WANT TO GET THERE?

TABLE 1. FOUR QUESTIONS OF TRANSITION MANAGEMENT.

Question Three involves the selection of a method to accomplish organizational change. This method should be consistent with the technological, political, and cultural systems of the organization. Unfortunately, while there is a large amount of scholarly work available on transition management methods, this area seems to suffer from a lack of cohesion and consolidation. This vast number of choices of transition model tends to overwhelm those persons planning change programs; moreover, it has been suggested that the individual models do not adequately describe the entire transition process. Thus, the authors have proposed a three category model based on the rate of transition, the shape of the management transition structure, and the method of influencing behavioral changes in the employees that will allow transition to occur. By selecting an appropriate method from each category, a hybrid transition program can be devised which is more likely to succeed than the utilization of any single method.

The fourth and the last question deals with whether the organization is willing to pay the price of transition. Obviously, there is a certain amount of upheaval and risk involved in transition. Part of the answer to Question Four deals with the amount of resources that the organization is willing to commit to the transition.

FACTORS INFLUENCING CHANGE

The process of communicating the need for the change to all levels of the organization is perhaps the most difficult problem which must be overcome. Management is often unable to communicate, in a proper and effective form, the need for change to all levels of the organization. This may be due to some of the following reasons:

* The lack of proper communication of the need of and plans for the proposed change;
* The lack of planning and coordination for the change;
* The unavailability of the proper resources to accomplish the change; and
* The presence of technological limitations that prevent the implementation of the best course of action for the proposed change.

Another problem is organizational resistance to change. Large organizations can be considered as a mountain of inertia which must be moved if it is to make a major transition. The members of the organization must be convinced that the transition is both necessary and inevitable in order for a successful change to occur.

Frequently, a catalyst is required to bring the necessary amount of support to the transition. In this sense, a catalyst is an event that signals the need for change. Unfortunately, this catalyst is oftentimes catastrophic in nature. For example, a decline in prices or a major shift in production technology could place an organization in an unfavorable market position. Also, a

major accident or even a near miss may convince organizations engaged in hazardous operations that they must change. While this catastrophic catalyst proposition may seem disturbing, it essentially states that transition is usually not done capriciously.

Also, an organization must have the right people to operate in a new environment created by a major transition. In a transition from R&D to operations, this consideration becomes extremely important due to the numerous differences between the two environments. One of the major differences is that in an R&D setting, the concept of creativity is highly prized and rewarded; this may not be the case in an operational state. Additionally, it has been found that project people generally do not desire to do operational work. Thus, the conclusion that can be drawn here is that some consideration must be made of the demographic makeup of the organization before any transition is initiated. Since most major demographic changes require a long lead time, this consideration needs to occur early in the transition planning.

R&D TO OPERATIONS TRANSITION MANAGEMENT

One thing in common with most transition programs is that they follow a life cycle process somewhat similar to the growth pattern of a project. For the specific transition of an organization from an R&D state to an operational one, the amount of variability in the product should be reduced to a

point that routine operations can be performed (see Figure One). In order for this to occur, the organization's way of conducting business must change. This will put pressure on the management system, because it will encounter tremendous changes during the transition period in order to make the desired transition (see Figure Two).

Following the model proposed by Quinn and Cameron (10), the different stages in transition could be defined as the entrepreneurial stage, the collectivity stage, the formalization and control stage, and the elaboration of structure stage. One major drawback to this approach is that, unlike organizations, a transition program should eventually end. In addition, the stages of the program should hopefully occur somewhat faster than the life cycles of the organization. For these reasons, we will combine the entrepreneurial and collectivity stages into a stage defined as the creativity phase. Furthermore, the formalization and control phase will be refered to as the control phase, and the elaboration of structure phase will be defined as the integration phase. However, since transition is meant to be completed within a definite time frame, a fourth step called the stabilization phase will be included to account for the termination of a transition program. The intent of this last phase is to give some insight into the point in time where the transition management program ends and the organization stabilizes into its new steady state. The correspondence between the Quinn and Cameron stages and the

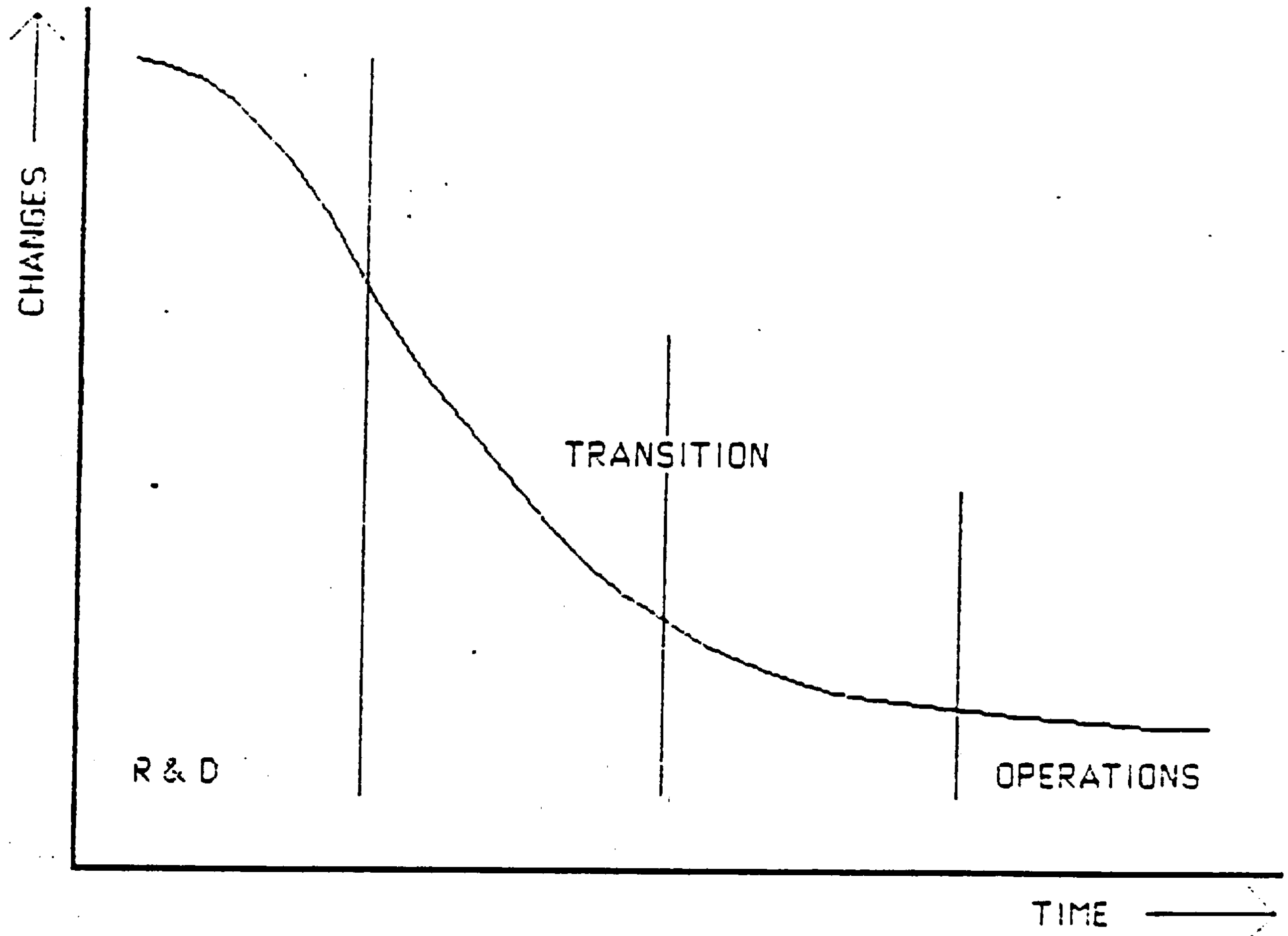

FIGURE 1. PRODUCT CURVE

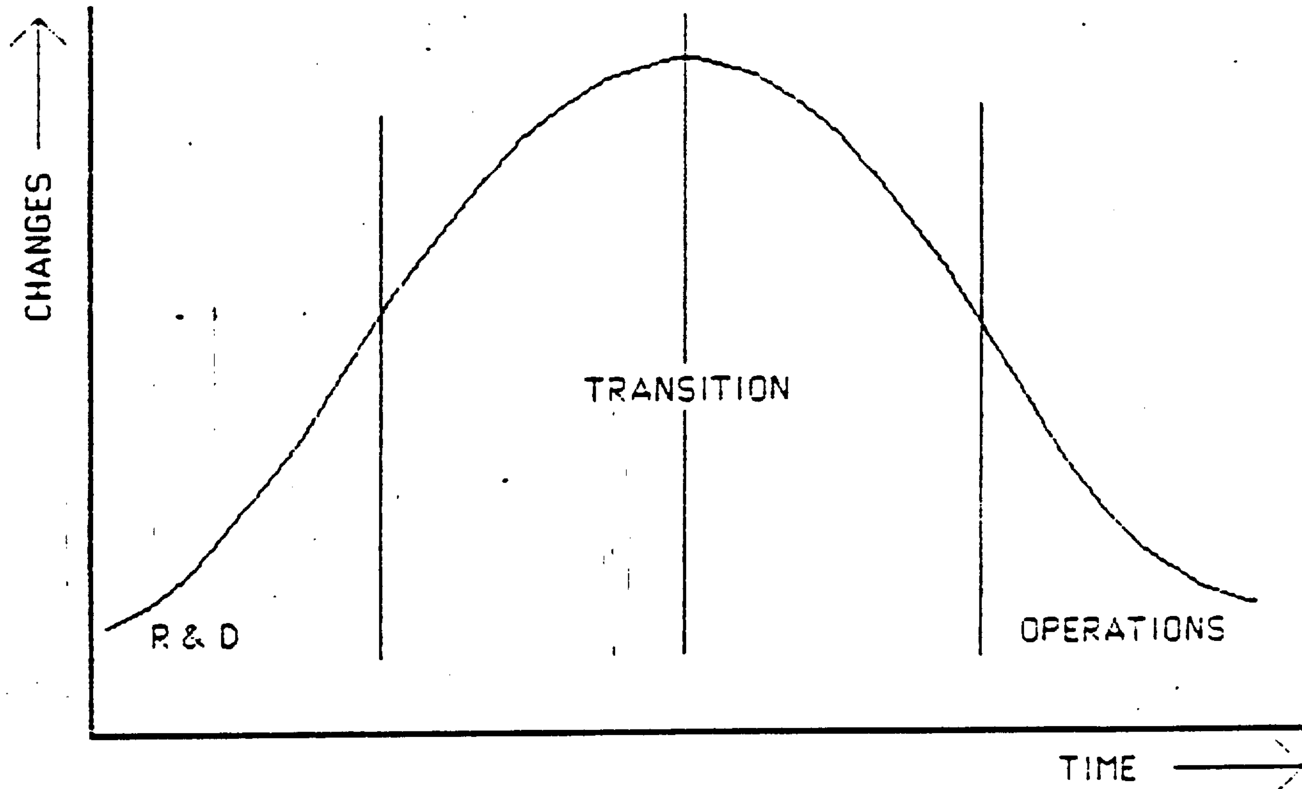

FIGURE 2. MANAGEMENT SYSTEM

phases develop herein is shown in Table Two. The four phase model is shown in Table Three, and is developed further in the following paragraphs.

CREATIVITY: TO ESTABLISH THE BEST SYSTEM

Generally, there are many uncertainties in the organizational environment which must be identified and controlled in order for a major change to be successful. This degree of uncertainty means that flexibility should be designed into the transitional structure so that the creativity of the people involved in the change effort is fully utilized (8, 11). Also, major resource commitments during transition should be made as late as possible and in a way that is consistent with the information available. Similarly, in order to significantly reshape an organization's culture, powerful psychological and political forces must often be overcome. In addition, the success of a change may well depend on the very group whose perceptions must be changed. So if a transition moves too quickly, it can undermine the essential strengths of the organization and easily alienate the people in the organization. Naturally, this will cause a loss of credibility for the transition program and severely hamper changing the culture of the organization.

The issues discussed here clearly support the fact that the technical, political, and cultural aspects of the organization must be changed whenever the organization

TRANSITION MANAGEMENT LIFE CYCLE MODEL	QUINN & CAMERON ORGANIZATIONAL LIFE CYCLE MODEL
I. CREATIVITY PHASE	I. ENTREPRENEURIAL STAGE II. COLLECTIVITY STAGE
II. CONTROL PHASE	III FORMALIZATION AND CONTROL STAGE
III. INTEGRATION PHASE	IV ELABORATION OF STRUCTURE STAGE
IV. STABILIZATION PHASE	

TABLE 2. COMPARISION TO TRADITIONAL LIFE CYCLES

I. CREATIVITY PHASE

Things to consider:
* Technical / Political / Cultural aspects of an organization as a resistance to change.
* Environmental analysis before endeavoring the change process helps in understanding the situation.
* Management flexibility leads to organizational success.
* Logical Incrementalism method of organizational change prepares everyone for the change process while achieving its objectives of transition.
* Systematic approach is the best method of changing a high technology organization.

Things to be done:
* Form/Implement a planning group.
* Determine the organization's change targets and strategy.
* Design specific events needed to point towards the need (or awareness) to change.
* Develop the organizational structure after the change.
* Formulate the timetable for change.
* Institutionalize the expectation of change.
* Formulate the goals for the organization state assessment.
* Emphasize experimenting before making final commitment to the change or process.

II. CONTROL PHASE

Things to consider:
* A guiding executive articulates the vision of the new organization and its transition goals.
* Top management must be involved in monitoring and control of change process.
* An effective leader helps people understand how their work contributes to objectives of the total organization.
* There is a increased need for a two-way communication in all spheres of change.
* Culture of organization must evolve in order to implement a new mission.

Things to be done:
* Implementation of the strategy for change.
* Emphasize on pattern breaking.

  Some of the tools availabe for management:
  * Training is a useful tool for change.
  * Recruitment can be used as a tool for change.
  * Retereat or gathering is another tool for change.
  * Task force is a useful approach for the change process.
  * Change agent acts to facilitate the change.

III. INTEGRATION PHASE

Things to consider:
* The employee involvement in problem solving and the making of new organization guarantee the success.
* Organizational change requires the commitment and support of the individuals and groups.

Things to be done:
* Decentralization of change program strategy making.
* Some people must be held accountable for the change process.
* Use rewards, intrinsic and extrinsic, as a change agent.

IV.STABILIZATION PHASE

Things to consider:
* Is the job really done.
* What tools and experience from transition can be used in the steady state.

Things to be done:
* Study the state of the organization and see if the change has been made in a feasible direction.
* Disband the working group involved in transition, if a feasible change has been made.
* Establish the proper needs of the evolved organization in terms of human and non-human resources.
* Effectively utilize the prized people who have been instrumental in accomplishing this goal of transition.

TABLE 3. THE FOUR PHASES OF TRANSITION MANAGEMENT

wishes to undergo transition (11, 12, 13). In addition, it suggests that transition awareness and commitment be created in incremental steps while simultaneously achieving progress towards the final state (6, 7, 8, 9). It also suggests that the management structure should be flexible in order to maintain creativity in the initial phases of implementation (6, 11, 12).

The essential job of the creativity phase is to analyze the existing state and, through the utilization of the four questions of transition management, plan a new state and a change program. Existing difficulties in the current system and the desired aspects of the new system need to be defined. After this is done, the technical, environmental and economic feasibility of the new system must be established (3). Also, sources of resistance must be explored and the areas affected by the potential change must be identified.

The responsibility of management is not only that of providing a creative climate, but is also that of finding a way to plan and implement the change within the framework of the proposed system. This responsibility translates into the planning of resource requirements, costs, schedules, interfaces, and support systems necessary to implement the change (1, 3).

In an R&D to operations transition, the people in the R&D environment should be comfortable with this phase since they are trained to find creative solutions to problems.

However, it should be remembered that their inherent culture causes them to be individualistic, which can cause problems.

In the first phase of the transition, a small group of people are normally involved who are highly motivated and in close contact with each other. The output and the personal satisfaction for a small group involved in a large change effort is usually high and that effect is conducive to the climate of creativity. However, as the number of people involved in the change process increases, problems may occur about who will assume leadership. This needs to be brought under control in order to maintain the objectivity of the change process.

CONTROL: TO MAINTAIN THE PURPOSE AND DIRECTION

During the second stage of the change process, a more formal and structured management system begins to emerge. This is probably the first point where a research organization will start feeling the effects of change and perhaps begin to experience discomfort with the change. The purpose of this stage is to strengthen the creativity process and provide a purpose and direction to all of the efforts required to make the necessary transition. At this stage, an autonomy crisis may develop, particularly for research-oriented people, and there may be some conflicts in the goals of different people in the organization. An important job of senior management at this stage is to provide a structured transition management system based on the framework evolved

in the creativity phase of the change process. By providing a structure, the senior management is in effect defining the future goals and directions for the organization.

Furthermore, management must communicate these goals to the entire organization. The success of the transition will be directly related to the degree with which the employees associate themselves with the objectives of the transition. This degree of association is in turn directly related to the success of management in conveying the goals and the reasons for their selection to their subordinates.

One of the purposes of providing a structure to an organization is to maintain a direction. The future success and direction of the organization is greatly based on the success of the transition. A transition program that is properly planned takes into consideration the effects of technical, political and cultural changes on the organization and provides methodologies for problem resolution. Task forces, involvement of a change agent, training, retreats, and meetings are some of the tools available to management. The proper utilization of these tools at the proper time is one of the main responsibilities of the those responsible for the change effort.

During this phase, the organization is informed of the desired new state and the method that will be used to achieve it. However, some people will resist the change and try to remain under the existing conditions. It is the task of management to reduce the alienation between the

individuals and the organizational goals and thus minimize the resistance to change. This alignment of the goals of the organization and the individuals is a difficult process, but will be more successful if the need for the change is properly communicated and well understood by all involved in the change effort.

The role of the chief executive is very important at this stage. The transition should not only have his/her complete support and attention, but this support and attention should be both visible and tangible. This is the time when the chief executive should assume responsibility for the formalized plan developed in the creativity phase. This role is that of a guiding leader who has to bring all of the various parts together in order to form one strong new vision of the emerging organization.

INTEGRATION: THROUGH COORDINATION AND COMMUNICATION

This is the phase where people begin to accept the change. The strength of this acceptance and support is greatly dependent upon the strength and support of the top management. It is a time when the senior management is setting up its sphere of influence over the transition. Because of the centralization of command in the previous phase, an autonomy crisis may well occur with the top management. This may in turn cause a lack of coordination between departments and rising tension. This is the time to delegate responsibilities and establish proper channels of

communication in order to keep the spirit and direction of the transition on track. In this stage, the delegation of responsibility for change takes place and accountability is assigned. However, this action may create some high level managers to build empires at this point. Furthermore, methods for monitoring, evaluating, and modifying the transition are put in place in this period.

STABILIZATION: RETURN TO STEADY STATE

This is the time when the transition ends and the organization stabilizes into its new steady state. Perhaps the first task of the transition period is to determine if the transition is really over. The organization may wish to continue some aspects of the transition structure into the new steady state. Similarly, some parts of the transition program may have to be disbanded. Whichever may be the case, some thought needs to be given to the disposition of the transition structure and then this disposition must be implemented. As a specific example, plans must be formulated and implemented to absorb the transition management team into the structure of the new era.

The organization should strive to have the termination of the transition be as smooth as possible. In addition, the employees need to be kept fully informed of the progress of the changes. It is during this period that the development of a sense of pride and identity with the new direction of the organization needs to be solidified. Also, it is during

this period that the rough edges in the new state of the organization can be smoothed. Some education will naturally have to be supplied to the employees in order to assist them in dealing with new tasks. As they learn new jobs, better ways of performing tasks will also emerge.

During the stabilization period, some effort should be directed towards the documentation of the transition. A formal history of the transition will prove invaluable to the organization when it undergoes its next transition. During the more active periods of transition, time may not have been available to write information about the change. However, during stabilization the pressure should be easing and attention can be directed towards this task.

In summary, Figure Three gives an overview of the phases on the change curve for the management system. The creativity phase is the birth and planning period. The stabilization phase is the death period of the transition in which the transition structure is disposed. The control and integration phases are the periods of the most activity since nearly all of the employees will be involved in these two phases.

IMPLEMENTATION: THOUGHTS AND PROCESS

As each change planned in the creativity phase awaits its implementation, the commitment of resources will remain a function of how well the change process and the environment is known and understood by those responsible for the

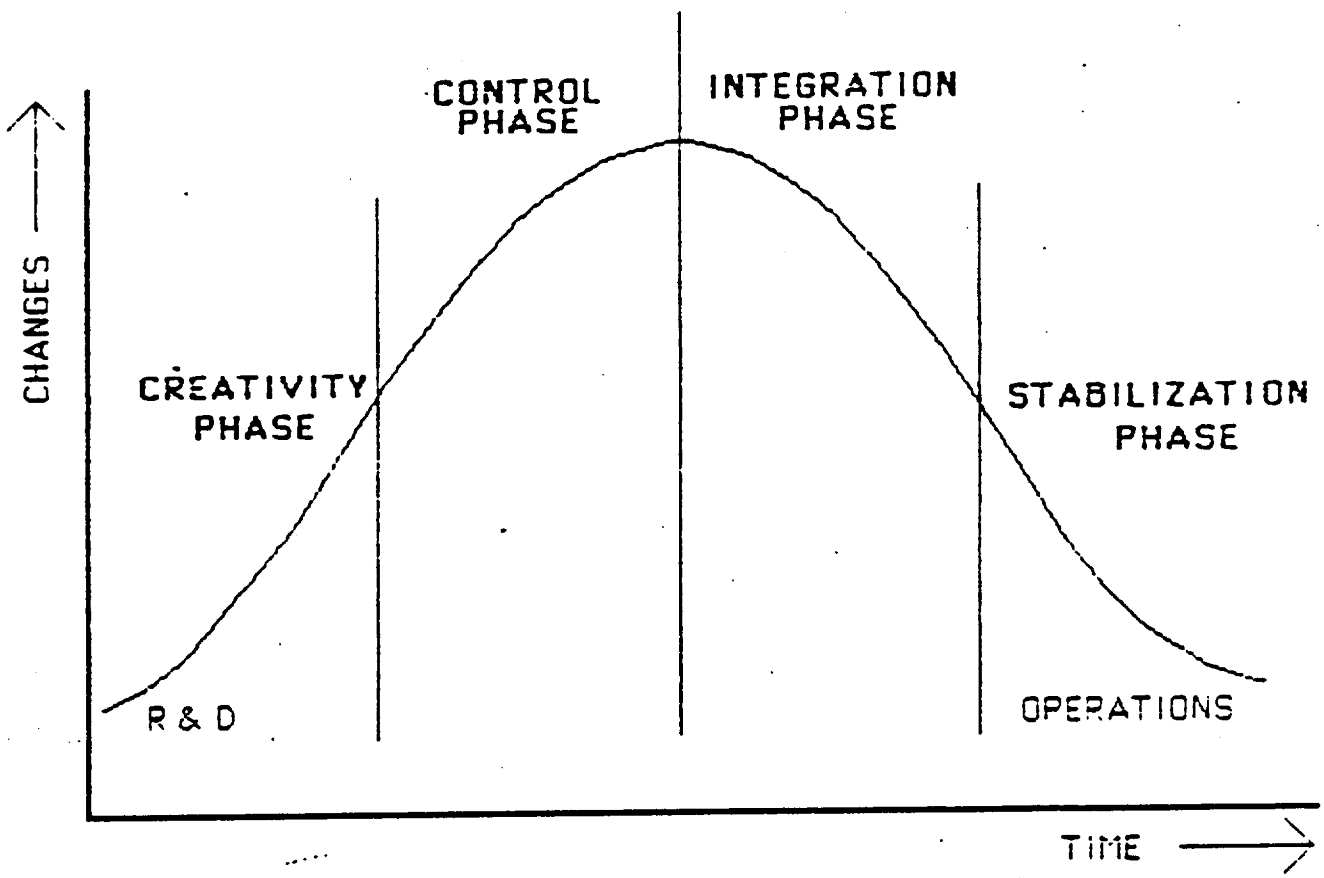

FIGURE 3. TRANSITION MANAGEMENT SYSTEM

transition. If all of the elements of transition are known and the outcome of the transition can be predicted, then an instantaneous change is reasonable to consider. In reality, such certainty is unusual. As the uncertainty of the situation, technology level, and the level of resource commitment increase, so does the need for careful analysis of the existing state, definition of the future state, and transition program planning. A highly complex environment warrants a comprehensive transition program testing phase before a total commitment is made if time and the situation permits. A critical issue in transition planning is the understanding of the life cycle of transition. The four phases of transition interact with each other, and all must be planned. The plan must include the integration of the four phases and a methodology for progressing through them.

SPECIFIC CONSIDERATIONS FOR THE R&D TO OPERATIONS TRANSITION

While the use of employee involvement in the transition program development process promotes creativity, innovation, and commitment to the transition, it should be realized that the employees are usually not specialists in the new environment. Specifically, R&D personnel usually will not have extensive knowledge about operations when they attempt to plan and R&D to operations transition. Therefore, proper guidance and a broad description of the change should be provided. For example, one way of educating R&D people about operations would be to show a side-by-side comparison

of an R&D organization and an operational one. Likewise, employees will know little if anything about transition management. It is the task of top level management to provide the education and communication necessary to make the transition period work. The direction of the planning process must be closely guided by top level management without hindering the innovative involvement of the employees. Once a transition management plan is decided, top level management must implement and monitor the plan. The resistance of the work force can be minimized if proper involvement and communication is used.

CONCLUSIONS

This paper has shown that an understanding of the transition life cycle model should assist management in the planning and implementation a successful change program. By modifying and extending the life cycle model proposed by Quinn and Cameron (10), a four-stage transition life cycle model can be developed that adequately describes the transition process. Also, planning a transition can be assisted through a careful analysis of the existing environment through the use of the four question format presented in this article.

Also, for the specific transition of an organization from an R&D state to an operational one, the amount of variability in the product should be reduced to a point that routine operations can be performed. In order for this to

occur, the organization's way of conducting business must change. This will put pressure on the management system, because it will encounter tremendous changes during the transition period in order to make the desired transition. This study has provided important data for those individuals and organizations who are contemplating change programs, especially those programs involving transition from an R&D environment to an operational one. This should prove invaluable to NASA's space shuttle program as it makes the transition from R&D to operations.

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APPENDIX V B.1

PREPARING NSTS MANAGERS FOR AN OPERATIONAL ERA

PREPARING NSTS MANAGERS FOR AN OPERATIONAL ERA

INTRODUCTION

The space shuttle program, currently the flagship of NASA's numerous programs, [had] been grounded since the Challenger accident in January, 1986. Although the accident manifested itself in the form of a hardware problem, a contributing factor according to the Roger's Commission was a breakdown in the organization's communications, decision-making, and control processes which permitted the shuttle to operate despite knowledge of this potential hazard. Even if there never had been an accident or a problem with the SRB joints, business could not have gone on as usual for NASA. Problems were apparent to both NASA and the public in the form of frequent postponements and delays. The waiving of NASA's own safety and inspection processes and the large amounts of overtime required to meet launch schedules were all symptoms which pointed to a larger problem. The problem was an organizational system which was not set up for the task of operating the shuttle in a routine, timely fashion and found itself overtaxed. The premise of this paper is that NSTS needs to transform itself from an R&D-type organization into a true operations-type organization. In particular, it discusses what subjects management needs to know in order to plan and implement the transition to the operational era as well as topics necessary for managing this new state. It also discusses and recommends training methods

which can best impart this knowledge.

NASA is currently managed using a project or R&D-oriented approach. This management approach has served NASA well over the years and has resulted in a steady stream of successful programs. However, all of these programs had characteristics which were conducive to the R&D type of management: all had a definite goal, an ending, and used only expendable hardware. The space shuttle program is different from all of these other programs: First, much of the hardware is reusable. Second, the program has no immediate end. Third, the flights are intended to be regularly scheduled, frequent, and on time. Last, the space shuttle program is a program whose life span is so long that the program can be considered non-ending. If the space shuttle is ever to fulfill its goal of routine, timely flight at reduced cost, it will have to be managed as a continuous process rather than a project. This requires operations management. This is not to say that NASA's present structures and processes are bad, but rather that they are expected to perform under circumstances for which they were never intended. They are the wrong tools for the wrong job.

NASA probably could continue to manage the shuttle program using the present structure and processes. However, they will be hard pressed to ever improve on their already scaled-back flight rate. This can have deleterious long-term consequences for the agency. First, NASA will no longer be the only alternative for launching satellites. A number of

international and even private organizations are expected to compete with NASA to provide launch services. This competition will be on the basis of price, quality, and service. This means that NASA, in a manner similar to American industry, will be forced to become more productive. Second, in this age of budgetary limits, NASA may find itself forced to make do with less money. Third, the world is changing at a rapid pace, and NASA must become a more flexible and adaptable organization if it is going to flourish in this uncertain environment. A by-product of improved adaptation will be a reduction in organizational and individual stress at NASA. Fourth, the space shuttle is a source of prestige for both NASA and the nation. Serious accidents and delays detract from NASA's image and could erode national support for space exploration. Finally, the space shuttle program has been operating in what could be described as a crisis management atmosphere ever since NASA declared it operational. If NASA is to continue to be a forward-looking organization, it must identify problems before they become crises and exploit opportunities to maintain leadership in space. If NSTS is to ever fulfill its destiny in the space transportation business, it needs to develop into an operational organization.

A successful operations-type organization requires operations-type people. Operations people are familiar with the tools of operations management and are comfortable with the structural, political, and cultural systems which drive

the operations function. There are two ways to obtain people with this background: hire outsiders familiar with operations techniques or train those who are not. The former option is available to NASA to a limited extent. As it hires new people for the NSTS, it can hire those who have experience in operations management or those who have formally studied it in school. However, most new hires will need to be there for years before they have the knowledge and/or management responsibilities to directly influence the organization. The most viable alternative, at least in the short term, is training NSTS's present managers.

PREREQUISITES FOR MOVING NSTS TO AN OPERATIONAL ERA

In order to evolve, NASA managers should have knowledge of change management skills and operational skills. The primary focus of change management skills is on getting from the present state (R&D) to the future state (operations). This includes understanding the characteristics of R&D management versus operations management and acquiring change management skills. Operational skills consist of the knowledge, quantitative tools, and practices which make operations organizations run. These skills primarily focus on managing the future state once NSTS has evolved. Since change management skills must logically precede the operations management skill, these will be discussed first.

R&D MANAGEMENT VS OPERATIONS MANAGEMENT

Knowing the differences between R&D management and operations management is an important first step in making the transition from one state to the other. First, with the present R&D approach to preparing the space shuttle, the only way to improve the flight rate is to work longer and harder. The alternative is to work smarter, not harder through the application of operations management techniques. Second, knowing the characteristics of R&D will help NSTS personnel better understand the present state and underscore the need for change; knowledge of operations management will help to better define the future state. Finally, managers need to realize that these two systems are fundamentally different.

Brah, et al (1986) have performed in-depth research into the characteristics of both R&D and operations management. They have identified differences in thirteen key areas (see Table 4.1): (1) The primary objective on an R&D organization is to further knowledge. An operational organization exists to produce a product or service at a competitive price. (2) R&D organizations tend to be nonhierarchical whereas operations organizations have a well-defined chain of command. (3) Power in an R&D organization is based on one's technical expertise or "expert power". The more highly valued the expertise, the more power that particular individual or group has. In an operations organization, individuals wield authority based on their position in the organization. (4) Leaders in R&D organizations basically

seek to provide a supportive atmosphere in which creativity can flourish. Operational leaders attempt to provide the motivation and guidance necessary to maintain production. (5) Operational organizations are generally characterized by limited resources, deadlines, standard operating procedures, and a chain of command; R&D groups generally have few short-term work pressures, are self-directed, and are decentralized. (6) Performance criteria for R&D people are hard to define and quantify whereas operations easily lends itself to quantification and evaluation. (7) In R&D, outstanding performance is rewarded with recognition and better assignments; outstanding performance in operations is rewarded with promotions. (8) Communication in an R&D organization tends to be informal and travels laterally and across hierarchies. Operations management stresses formal communication which travels up and down the command chain. (9) An operations information system generally deals with data of past and current activities -- a short-term time horizon. R&D information concentrates on the future. (10) R&D projects generally require a long-term commitment in both time and resources. Operations requires that schedule changes be accommodated on short notice. (11) The R&D work environment is more collegial than the competitive, goal-oriented operations work environment. Operations environments emphasize structure and control; R&D groups usually permit rules to be bent. (12) The R&D corporate culture is based on peer recognition and intrinsic job

satisfaction. Operations people tend to be motivated more by extrinsic rewards. (13) R&D organizations are made up mostly of technical professionals who tend to attach more loyalty to their profession than to the organization. Their political influence is derived from their expert power. Operations people identify more with their organization. Here, political influence is based on the ability to allocate resources.

CHANGE MANAGEMENT SKILLS

Organizations do not change by themselves -- people change them. There are several reasons why change management skills are important for managers to have. First, "part of every manager's job is to plan, initiate, and manage change" (Edgar Schein as cited in Beckhard and Harris, 1977). Second, in this age of rapid change, only those organizations which are adaptable to change are going to prosper and survive. This ability to manage organizations through change will become the yardstick by which managers will be judged. Third, organizational changes are difficult to implement. People and organizations are resistant to change, unanticipated problems frequently can arise, and actions can lead to unintended consequences. Systematic planning, implementation, and evaluation of the transition program may not guarantee success but will certainly improve the chances of success. Organizational change also can have a human toll. Managers who seek to balance these human needs with those of the organization can markedly smooth the transition

process. Fourth, change is a process and a process must be managed. The business of the organization cannot be put on hold waiting for the transition program to finish. Management must know how to minimize the disruption of the day-to-day business during this transition period.

Training can teach managers "how change takes place, how to create desirable future conditions, and how to create those conditions without undue financial and human strain" (Ackerman, 1986). A logical place to start is with the characteristics of change --why it is necessary, the sources of change, the different types of change, and how these factors can influence one's approach to managing it. For instance, the strategy of a firm with major financial and competitive problems would not be the same one used for a healthy company attempting to reposition itself in the marketplace.

The success of a change program often depends on how the human side of it is handled. Managers need to be trained in how change affects people. Typical reactions of people to change are fear, resistance, anger, withdrawal, and anxiety. People can respond to change in one of four ways: neutral, negative, affirmative, or counter-productive (Schaller, 1972). Managers must become aware of these reactions, learn to anticipate them, and know how to respond to them.

Managers need to know the steps involved in developing a change program. Most models used to describe organizational change have some variation of the following three steps in

common: (1) Diagnose the organization, (2) implement the transition, and (3) manage the changed state. The commonly used four-question change model can help in planning the change. It basically asks (1) Where are we now? (2) Where do we want to be? (3) How are we going to get there? and (4) How badly do we want to get there? (Brah, et al, 1986).

Diagnosing the organization consists of defining both the present and the desired future states of the organization. Adequate time and thought must be given to the diagnosis phase if one is to avoid treating symptoms instead of causes. Defining the desired future state of the organization is important because it becomes the goal of the transition program. Defining the present state is important because it is used to identify specific groups, attitudes, policies, and structures within the organization that need changing in order to reach the future state.

Implementing the transition involves creating a transition plan, putting it into action, and evaluating it. The planning process determines what needs changing, where to make the change, and how to make the change. An important element in planning how to make the change is the activity or process plan. This plan details all of the activities to be completed, links them in a logical sequence, assigns time estimates for the completion of each activity and lists those people involved in carrying out each activity.

Change methods should not be chosen until all of these preliminary steps are complete. There are hundreds of change

methods from which management can choose. Common methods include managerial directive, management by objectives (MBO), and organizational development (OD). One of the most commonly used is training and development.

Evaluation is the final activity in the implementation phase and can provide feedback, discover problems, and suggest improvements for future programs.

The final step in the change process is managing the desired future state. A clear danger here is the tendency to revert back to the old way of doing things. The primary task of management becomes one of preventing this from occurring through the use of performance reviews and reward systems.

One of the biggest tasks of managers during tranistion programs is overcoming employee resistance. Managers must be familiar with such techniques for overcoming employee resistance as employee participation in the planning of change, open communication, regulating the amount of change introduced, and using informal leaders to get resisters to accept the change program. They should know that middle management is the most resistant to change and focus special emphasis on them. Managers themselves are subject to the stresses that change can bring about, so courses in wellness and stress management should also be taught as part of a personal change management program.

Today, the trend in organizations is for more worker input into corporate decision-making. Sitton's (1988) study shows that the post-transition state is significantly more

participative and less bureaucratic and authoritarian. Therefore, managers will need to know about matrix/participative/team management. These management styles will require an awareness of group dynamics, conflict resolution, and interpersonal communication. Good communications skills are also vital to the success of transition programs. Managers must be able to articulate the organization's goals to their subordinates, answer any questions concerning the change, and listen carefully to their concerns and suggestions.

OPERATIONS TOPICS

By itself, management's readiness to change to an operational era will not be enough to bring about organizational change. One must also be capable of managing the new organization using operational techniques. Four basic areas of operations would be appropriate for NASA: quantitative methods, operations management, logistics, and safety, reliability, and quality assurance (SRQA).

QUANTITATIVE METHODS

Quantitative methods are the mathematical tools used to improve operational decision making. Operations management, logistics, and SRQA all have mathematical foundations. One of the most useful tools is probability and statistics which is used extensively in reliability and quality assurance programs. Statistical decision analysis is a method by which

the risk of a given course of action can be minimized or the possible gain maximized. Linear programming (LP) and goal programming are methods for modeling real-life systems to determine how resources should be allocated. Its uses include logistics, inventory control, and scheduling. Queuing theory is used to determine the best way to process a number of customers (e.g. space shuttles) through one or more service points (e.g. orbiter processing facilities) in the shortest possible time. One of its primary uses is for scheduling. Since NASA lives in a world of limited funding, cost analysis and engineering economy can be used to evaluate the trade-offs between two or more competing systems. Furthermore, engineering economics can be used to better help NSTS determine the cost of each mission. Simulation is a means of mathematically simulating the operation and performance of real-life systems on a computer. Simulation permits managers to know how a system will act "on paper" before making a large commitment of resources.

SRQA

The safety, reliability, and quality assurance (SRQA) function is of paramount importance to NASA. Concern for safety has traditionally permeated the NASA culture. Human lives, billions of dollars in hardware, and national prestige were at stake. Unfortunately, the "extensive and redundant" safety program in place during the Apollo program had been allowed to become "ineffective" after the first four space

shuttle flights (Rogers Commission, 1986). At the behest of the Roger's Commission, NASA was to place "top-to-bottom" emphasis on SRQA. In fact, the Roger's Commission Report noted that "if the [SRQA] program had functioned properly, the Challenger accident might have been avoided." In the future, purchasers of launch services will demand reliable flights, or they will have someone else launch their multi million dollar payloads.

Reliability is the probability that a component will perform its intended function for a given period of time under a given set of conditions. Quality assurance is concerned with providing an item or service which will meet a specified standard. The two concepts are closely related since one cannot expect high reliability in an item built with substandard components or improper assembly. Reliability is concerned with minimizing the frequency of failure; safety is concerned with minimizing the scope of human injury if a failure should occur. The relationship between these three concepts is that high quality leads to increased reliability which in turn promotes safety. (Lewis, 1987; Dhillon, 1985; Duncan, 1986).

QA typically includes the derivation of sampling plans which are used to accept or reject large lots of items based on relatively small samples and control charts which determine if a process is out of control. Other functions of QA are rectifying inspections whereby rejected lots are reinspected and all defective items are replaced and

hypotheses testing in which two or more items are compared to determine whether item A was stronger, or lasted longer, or was better in any way than item B.

Reliability is concerned with determining failure rates of systems, how loads imposed on systems affect reliability, how reliability can be improved through the use of redundancy, and how preventative maintenance can extend the life of a system. Other topics in reliability include fault tree analysis which is used to determine the causes of an undesired event and how to compensate for human error in the operation of complex systems.

OPERATIONS MANAGEMENT

Operations management is a broad field which is concerned with providing a product or service in the most efficient and effective manner. It is frequently referred to as production/operations management (P/OM) since most of the concepts evolved in industrial settings, but they are equally applicable to operations in the service sector. Effective management of an operations organization requires that managers know P/OM techniques and tools.

One of the most important topics in P/OM is designing for production. The best approach to this is to "get the operators into the design and the designers into the operation" (Hunsucker, 1986). A case in point here are the problems that a late manifest change by JSC can have on KSC. Process design involves listing the chronological sequence of

all operations, inspections, time allowances, and materials [including information] used in performing a service or making a product -- from raw material to finished product. The purpose is to identify ways of working faster and easier, i.e. working smarter, not harder (Niebul,1985). Demand forecasting is used to predict future demand for a product or service, e.g. the number of satellites expected to require launch services. This forecast is extremely important since it serves as the basis for the production plans and inventory systems. The aggregate production plan (APP) and the master production schedule (MPS) determine how many units of a product or service (e.g. how many DOD missions, space station missions, etc.) will be produced. Manufacturing resources planning (MRP) is a system used to ensure that raw materials (e.g trained mission specialists, software, test procedures, technicians, etc.) are ready when a production run (mission) is scheduled. Operations scheduling and production control deal with the sequence in which items are to be produced or tasks performed. Effective inventory control seeks to provide an exact match between supply (shuttle flights) and demand (satellites to be launched).

LOGISTICS

Although it is frequently associated with the resupply of military forces, the field of logistics is concerned with designing a product, service, or system that meets the desired requirements at the lowest **lifetime** cost. Logistics

looks at the total product from cradle (conceptual design) to grave (disposal). It not only looks at hardware, but producibility, ease of maintenance, the number of spares to stock over its lifetime, and anything else that will impact the use and cost of the product.

Logistics is a major problem with the space shuttle program. The purchase of spare parts was deferred repeatedly, resulting in much higher prices paid later for these spares. Also, it resulted in the cannibalization of parts from one orbiter to another and back again. This caused time and money to be spent for removing, reinstalling, and retesting them for the next flight. This also increases the risk of equipment failure since there is an increased chance of damage with more handling. It should be noted that 45 of about 300 required parts on Challenger were cannibalized (Rogers Commission, 1986).

THE ROLE OF TRAINING IN TRANSITION MANAGEMENT

Training activities are one of the most common change methods available to the organization seeking change. They are important for a number of reasons. First, they are an integral part of most other change methods as well as being a method of change in their own right. To succeed, change programs must be systematically planned, managed, and monitored. This requires people familiar with such areas as the principles of organizational change, how to diagnose organizational problems, how to win over those resistant, how

to choose the proper change method, and so on. Second, today's increased knowledge requirements make employee obsolescence inevitable at all levels of the organization right up to the CEO. Third, training is important because in today's competitive world, people are often the only difference between the performance of two organizations. Firms can purchase the same state-of-the-art equipment; organizational structures and processes can be copied. Investing in human resources must be given the same priority that investments in capital equipment have traditionally garnered. Finally, while training is extremely important in organizational change, it can also be extremely expensive. Training costs of over $30,000 per person are not uncommon. Managers must ascertain how their training dollars are being spent. Managers need to be aware of what training can do for them and their departments. The remainder of this paper discusses the three kinds of learning, the effectiveness of various training techniques, and concludes with recommendations for training NSTS personnel in these proposed subject areas.

THREE TYPES OF LEARNING

Learning is a relatively permanent change in behavior. Trainers attempt to define desired behavioral objectives and then design the learning environment to bring about these desired behaviors. One simple, yet popular training model classifies learning into three types: (1) change of

knowledge, (2) change of skill, and (3) change of attitude. Knowledge deals with the cognitive domain of an individual which permits him to learn and recall facts, concepts, and principles. It can be measured by tests. Skills deal with the psychomotor domain and involve neuromuscular activity as well as problem-solving and interpersonal communication. Usually, skills can be measured by the output produced, e.g. the number or quality of items produced. Finally, attitudes involve the affective domain, which includes the formation and exercise of values, attitudes, and feelings. Measuring changes in attitudes is difficult but is usually reflected by changes in productivity or product quality. Knowing the type of behavior change desired is an important factor in choosing a training method. [Simpson, 1983, Warren, 1969]

TRAINING TECHNIQUES

Once it is determined what subjects need to be taught, the focus shifts to what is the best way to teach them. There are hundreds of training and development techniques available to organizations. Huczinski (1983) lists over 300 training and development techniques. Determination of the "best" method is dependent on many factors including the subject to be taught, the capabilities of the trainees, the size of the group to be taught, the size of the training budget, and the location of the training sessions. Despite the hundreds of training methods available to trainers, only a few are used to any great extent. These include lectures,

conferences or discussions, programmed instruction, case studies, role playing, business games, and sensitivity training.

Training Method Effectiveness

The appropriateness of a particular training method depends on many factors. Simpson (1983) suggests choosing a training method on the basis of the type of change component desired, i.e. knowledge, skill, or attitude, the complexity of the subject matter, and the resistance of the learners to the subject matter. He believes that knowledge components are best handled using methods that permit self-paced learning. This could include activities such as assigned reading or programmed instruction. Skill training favors a learn-by-doing approach where the trainees interact with the same types of machines and people that they will deal with on the job. Finally, for attitude changes, he recommends "an experiential approach designed to evoke specific behaviors and to provide continued positive reinforcement of a particular attitude". The more complex the subject matter, the more interaction the learner must have with the subject matter; as learner resistance increases, so does the need for planned interaction between learners.

Neider (1981) took a survey of training directors who ranked the effectiveness of nine training methods in achieving six behavioral objectives: knowledge acquisition, knowledge retention, problem-solving skills, interpersonal

skills, changing attitudes, and participant acceptance. In general, the most effective techniques for knowledge components (as defined by knowledge acquisition and retention), are programmed learning, conferences, and case studies. Likewise, for changing attitudes and developing interpersonal skills, role playing and sensitivity training are the most effective.

TRAINING TECHNIQUES FOR NASA

The first part of this paper suggested six topics that NSTS personnel should be familiar with in order to change from a R&D-type organization to an operations-type organization. Appendix V B.2 shows the recommended content of these subjects along with those personnel who the UH team thinks should be targeted for this training. It also lists estimated training times.

Everyone at NSTS and in their support organizations need to be familiar with the difference between R&D (the present state) and operations management (the future state). They need to know why these two organizational forms require different structures, controls, people, and culture. This is because everyone needs to be pulling in the same direction. Knowledge of these two systems will help them to understand why the change is necessary and the goals of the future state. Since familiarity with this subject needs to extend throughout NSTS, the lecture (probably on videotape or TV) would be the most cost effective way of reaching this size

audience spread out over the various centers.

Change management skills also need to be taught in varying degrees throughout the entire organization. Senior managers will need the most extensive training in this area since they must be concerned with the entire change process from planning to evaluation. Lower level managers would at least need to have implementation skills. The rest of the NASA organization involved in the change will require a short background course in the goals of the change program, why the change is being made, and how the change will be brought about. The intent will be to enlist the organization's support, calm fears, and solicit feedback. Management trainees are also in line for extensive training in change management. This is because they are NSTS' leaders of tomorrow and they also will probably serve on the transition team.

All top and middle managers will need to be taught the characteristics of change, especially how to change the pace of the transition program and how people and the organization react to it. Familiarity with the various change models and the steps of a change program is a must for senior managers. The lecture method will suffice for teaching the knowledge component in these areas. However, training managers to deal with people's reactions change will require learn-by-doing techniques such as role playing or case studies. Likewise, the best way to reinforce the knowledge gained from lectures in planning, implementing, and evaluating a change program is

to have the managers use business games or case studies to simulate their own change programs. A major part of the planning process involves setting up a network showing activities in logical succession and their required completion dates. This may be one area where little training will be required since NASA management is already familiar with project management techniques (e.g. PERT/CPM).

Other important skills include communications, leadership, motivation, overcoming resistance, group processes, and participative management. A lecture for presenting facts and theory followed by a learn-by-doing approach such as role playing or discussion would seem to be effective for these topics. Role playing or sensitivity training would probably be the most effective for developing interpersonal skills. However, sensitivity training is expensive, and this could limit its use to senior management. Furthermore, it may not be an effective approach for engineers, who are generally more comfortable dealing with facts than feelings.

In training managers in operations subjects, the point to keep in mind is that an extensive background in operations management is not required in order to apply these techniques. The key is to have the manager recognize a problem as a candidate for solution using an operations management technique; the problem itself can be solved by a subordinate or a consultant who has the requisite expertise. Management must know enough about quantitative methods to

communicate their needs to those persons with the expertise in using them to solve problems. Hence, their training time is only about one quarter that of the management trainees who will eventually have an active role in the future, operational NSTS. Since management will only require overview, lectures will suffice. Lectures (typical classroom setting) or programmed instruction will be best for the management trainees since this material has a strong knowledge component.

While most of the NSTS must always perform their jobs with safety in mind, management must have enough knowledge of safety, reliability, and quality assurance (SRQA) to ensure that this function is being carried out. A brief course is adequate for them because they only need to know enough to communicate with SRQA people within NSTS and industry. Management trainees, on the other hand, can expect to take an active role in the SRQA function. This topic has a strong knowledge component so programmed instruction, reading, or a lecture are good methods to use.

All NSTS management and personnel will need to be familiar with, but not experts in, the techniques of operations management. Again, they will need to know enough to understand what others are talking about when presented with proposals performed using these methods. For management trainees, extensive classroom type lectures or programmed instruction will be the best. For the rest, brief overviews via live or taped lectures will be adequate.

Designing for production calls for training which brings design and operations people together so that each side develops an understanding of how they affect each other. The best way would be through conferences, cross-training within NASA, or temporary on-the-job training in industry. The two latter methods have the drawback of permitting only a limited number of people to be trained due to the high costs involved. The few people who may be able to take advantage of a program of this type may not be numerically significant to affect the NSTS organization. However, this would have much more impact on NSTS if those chosen for this program were identified as high-potential people.

The subject of logistics would be taught to the same groups using the similar methods to that were used to teach operations management.

CONCLUSION

NSTS is going to have to change from a R&D organization to an operational one if they ever hope to increase the flight rate of the space shuttle. To increase the chance of success for this change, they must train their people to be good change managers as well as good operations managers. A good change manager at NSTS will have to know how R&D differs from operations and how to plan, implement, and evaluate change programs. A good operations manager will need to know operations management techniques, logistics, and SRQA.

Training is expected to play an increasingly important role in helping managers acquire these skills. For the most part, these skills can be taught using lectures to cover the theory followed up in many cases by learn-by-doing techniques such as role playing, business games, or case studies to reinforce the theory. For most managers, a short overview of these topics will suffice; for management trainees, who will be managing the future, fully operational NSTS, more extensive training will be required.

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APPENDIX V B.2

TRAINING TOPICS FOR NSTS

TRAINING TOPICS FOR NSTS

1. R&D vs. Operations Management

Trainee	Training Time
All of NSTS	3-6 hrs

- Objectives and targets
- Organizational structure
- System Hierarchies
- Leadership behavior
- System management
- Performance criteria
- Reward system
- Communication system
- Information system
- Flexibility
- Work environment
- Cultural climate
- Political climate

2. Change Management Skills

Trainee	Training Time
Senior management	15-20 hrs
Management trainees	15-20 hrs
The rest of NSTS	4- 5 hrs

- The characteristics of change
  + Reasons, sources, types, pace, how people & organ. respond
- The change process
  + Change models
  + The steps of change
- Managing conflict
- Overcoming resistance
- Stress management

3. Overview of Quantitative Methods & Their Interpretation

Trainee	Training Time
Senior management	4- 5 hrs
Management trainees	15-20 hrs

- Probability and statistics
- Statistical decision analysis
- Linear programming and goal programming
- Queing theory
- Cost analysis/engineering economy
- Simulation

4. Overview of SR&QA and its Interpretation

Trainee	Training Time
Senior management	4- 5 hrs
Management trainees	15-20 hrs

- Statistical process control
  + Sampling plans
  + Rectifying inspections
  + Control charts
  + Hypothesis testing

- Reliability
  + Reliability & failure rates
  + Testing for reliability
  + Reliability vs. loads, capacity
  + The use of redundancy to improve reliability
  + Preventive maintenance and reliability
  + Failure interactions between components
  + Fault trees
  + Human factors

- Safety

5. Overview of Operations Management Methods & their Interpretation

Trainee	Training Time
Senior management	5- 7 hrs
Management trainees	20-30 hrs
The rest of NSTS	4- 5 hrs

- Design for production
- Process design
- Job design
- Material handling
- Demand forecasting
- Aggregate production planning and master production scheduling
- MRP
- Operations scheduling and production control°
- Inventory control

6. Logistics

Trainee	Training Time
Senior management	3- 4 hrs
Management trainees	10-15 hrs
The rest of NSTS	4- 5 hrs

- System/equipment operational requirements
- Maintenance requirements
- Design liason
- Testing and evaluation

- Industrial logistics (set-up & testing in the field)
- System operational support (in the field)
- Logistics support management

Trainee	Total Training Times
Senior management	34 - 43 hrs
Management trainees	78 - 111 hrs
The rest of NSTS	15 - 21 hrs

NOTE: Training times are estimates which will probably change once courses are planned in more detail.

APPENDIX V C

TRANSITION MANAGEMENT:
PLANNING A COMPLEX R&D TO OPERATIONS CHANGE

TRANSITION MANAGEMENT: PLANNING A COMPLEX R&D TO OPERATIONS CHANGE

SYNOPSIS

This paper investigates the initial planning process for the transition of an organization from a Research and Development (R&D) environment to an Operations environment. Using a developed transition life cycle model, the paper demonstrates a four step analysis of the management of the transition. Further, the paper suggests the utilization of existing methods for achieving a smooth transformation under various levels of technical, political, cultural, managerial, and economic uncertainties. Finally, the paper lists possible courses of action and considerations for the transition once the initial planning stage is completed. The concepts herin were used to begin planning the change, from R&D to Operations, of the Space Shuttle Program at NASA.

TRANSITION MANAGEMENT: PLANNING A COMPLEX R&D TO OPERATIONS CHANGE

INTRODUCTION

Any organization wishing to undergo a major transition, such as moving from a Research and Development (R&D) environment to an Operations environment, should organize the process by which it changes. Human nature's tendency to cause people to resist change forms a foundation on which this need is established. Although the disturbance caused by change in the present system may be necessary, it is not desirable to see the disturbance grow to a size which may consequently disrupt the steadiness of the organization. The magnitude of the allowable excitement depends upon the amount of shock the Political/Cultural/Technical/Managerial/Economic system of the organization can absorb without causing instability. This line of reasoning instinctively suggests that whenever a change is in order, it must be carefully planned in the sense that it considers all of the relevant dimensions of change. Although the magnitude of the change process can be and possibly is different for different organizations, one thing such changes have in common is that they follow a life cycle process. As presented in Figure 1, the life cycle begins with a slow start, accelerates to gain some momentum, and finally slows down again to phase out the completion process into the desired established surroundings. As a note to Figure 1 (and later in Figure 2), the graph(s) need not be symmetrical as the magnitude of the change during one phase may or may not be equal to the magnitude of the change in its "mirrored" phase. As with any project, there is a beginning, a growth, a decay, and an end. The management of transition follows the same

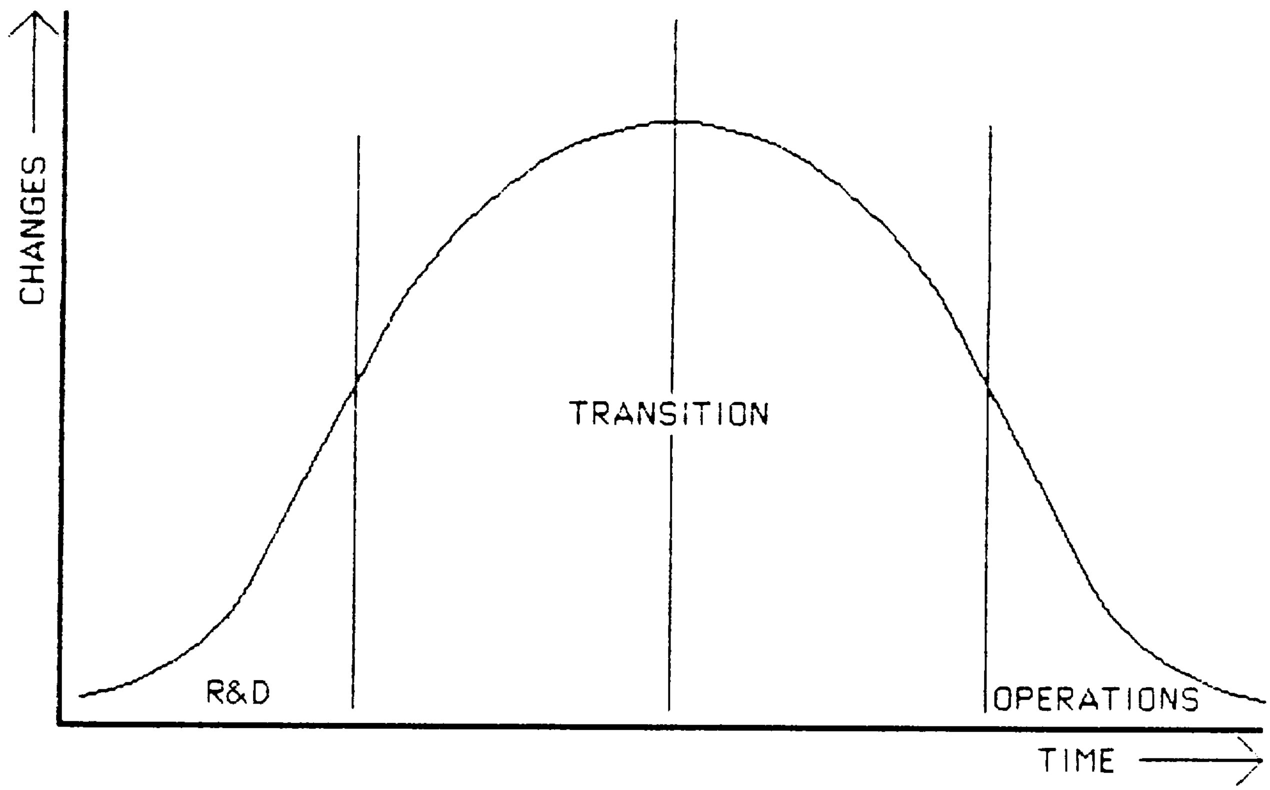

FIGURE 1. TRANSITION CURVE.

life cycle [4].

Quinn and Cameron did an extensive literature search on the models addressing organizational life cycles [16]. They integrated nine different life cycle models and described four basic stages (Entrepreneurial, Collectivity, Formalization and Control, and Elaboration of Structure), on which the organization was presumably based. The one major short coming of this organizational life cycle as applied to transition, is the absence of a termination stage. This stage may not be necessary nor desirable in the organizational life cycle, but termination is extremely important in the life cycle of transition management. Unlike the case of an organization, where it may be irrelevant to think of phasing out, one expects the transition to end.

The authors have developed a four phase Transition Life Cycle Model [4]. The four phases are the Creativity Phase, the Control Phase, the Integration Phase, and the Stabilization Phase. Table 1 lists the different considerations and actions to be taken during each of the different phases. Incidentally, the phases of the transition life cycle are also in phase with the three states of the familiar Kurt Lewin's conception prevailing in the literature: Unfreezing, Change, and Refreezing of the planned transformation. In summary of the four phases of the model, Figure 2 gives an overlay of the stages on the change curve for the management system. The creativity phase is the birth and planning period. The control and integration phases are the periods of the most activity since nearly all of the employees will be involved in these two phases. The stabilization phase is the death period of the transition in which the transition structure is disposed.

TABLE 1. THE FOUR PHASES OF TRANSITION MANAGEMENT

I. CREATIVITY PHASE

Things to consider:

- o Technical / Political / Cultural aspects of an organization as a resistance to change.
- o Environmental analysis before endeavoring the change process helps in understanding the organizational situation.
- o Management flexibility leads to organizational success.
- o Systematic approach is the best method of changing a high technology organization.

Things to be done:

- o Form / Implement a planning group.
- o Determine the organization's change targets and strategy.
- o Design specific events needed to point towards the need (or awareness) to change.
- o Develop the organizational structure after the change.
- o Formulate the timetable for change.
- o Institutionalize the expectation of change.
- o Formulate the goals for the organization state assessment.
- o Emphasize experimenting before making final commitment to the change or process.

II. CONTROL PHASE

Things to consider:

- o A guiding executive articulates the vision of the new organization and its transition goals.
- o Top management must be involved in monitoring and control of change process.
- o An effective leader helps people understand how their work contributes to objectives of the total organization.
- o There is an increased need for a two-way communication in all spheres of change.
- o Culture of organization must evolve in order to implement a new mission.

Things to be done:

- o Implementation of the strategy for change.
- o Emphasize on pattern breaking.

  Some of the tools available for management:
  - o Training, or re-training, is a useful tool for change.
  - o Recruitment can be used as a tool for change.
  - o Retreats or gatherings are other tools for change.
  - o A task force is a useful approach for the change process.
  - o Change agents act to facilitate the change.

TABLE 1. THE FOUR PHASES OF TRANSITION MANAGEMENT (continued)

III. INTEGRATION PHASE

Things to consider:
- o The employee involvement in the problem solving and in the making of a new organization aids in a higher probability of success.
- o Organizational change requires the commitment and support of the individuals and groups.

Things to be done:
- o Decentralization of the change program strategy.
- o Some people must be held accountable for the change process.
- o Use rewards, intrinsic and extrinsic, as a change agent.

IV. STABILIZATION PHASE

Things to consider:
- o Is the job really done?
- o What tools and experience from transition can be used in the steady state?

Things to be done:
- o Study the state of the organization and see if the change has been made in a feasible direction.
- o Disband the working group involved in transition, if a feasible change has been made.
- o Establish the proper needs of the evolved organization in terms of human and non-human resources.
- o Effectively utilize the prized people who have been instrumental in accomplishing this goal of transition.

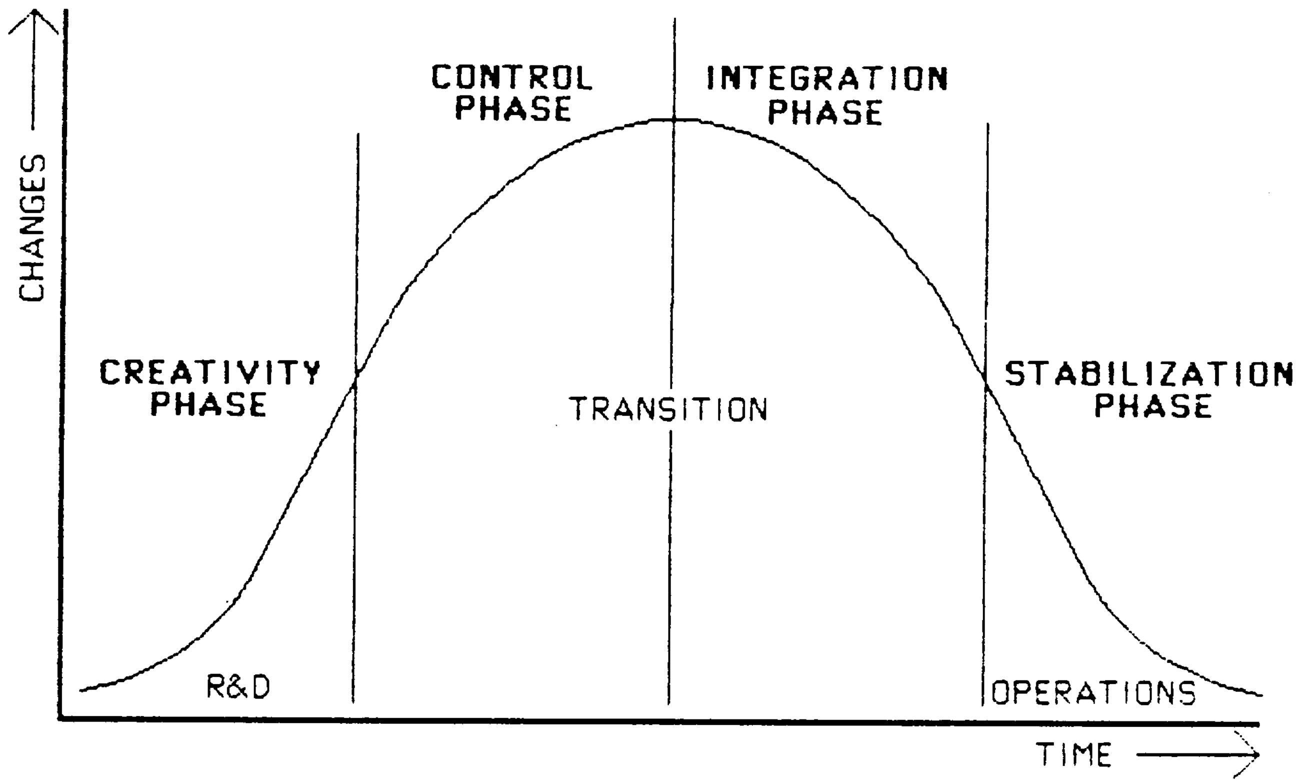

FIGURE 2. TRANSITION CURVE WITH OVERLAY OF LIFE CYCLE PHASES.

This article outlines some strategic considerations in accomplishing the transition from R&D to Operations. One important consideration in making such a major reorganization is that of understanding the present and the desired working environment of the organization. The understanding of these two conditions forms the basis on which the rest of the planning is based. This paper examines the two states, R&D and Operations, before and after the transition. It also suggests methods for achieving the smooth transformation under various levels of technical, political, cultural, managerial, and economic uncertainties.

BACKGROUND PROBLEMS

The research on this subject matter was inspired, and in fact sponsored, by the National Space Transportation System (NSTS) of the National Aeronautics and Space Administration (NASA). The thoughts presented in this paper were used as a basis to begin the planning of a major transition at NASA. Along with other concepts presented by the research team, see Hunsucker, Law, and Sitton in [13] for example, these concepts serve to provide structure, formulation, and organization to a large complex problem, that of moving the Shuttle Program to an operational era. Operations is used here in the context of sustained routine timely space flight over a long duration of time with an increased flight rate of the shuttle. While NASA has always been concerned with flying and flying safely in space, the shuttle program is the first NASA program with such a long duration that it has no foreseeable end. Actually this transition is quite unique for essentially few organizations have made a change equivalent to the

proposed movement of NSTS. The complicating factors in this movement include the size and complexity of the organization along with its complete public exposure. The situation has been further complicated by the space shuttle Challenger's accident in January, 1986. Adding to the difficulty is the concept that while many organizations move a specific product from R&D to production, on very few occasions has the entire organization made this movement. In addition the product under consideration, the service of flying routinely in space, is one for which there is no previous experience base. Furthermore, in a rather exhaustive literature search, no specific reference was found which dealt with the transition of an organization from R&D to Operations.

Using over 170 articles somewhat related to the task at hand as a beginning to the research, interviews were conducted with 19 major organizations which had undergone significant transitions. These interviews were conducted over the period from January 1985 to January 1989 [12a,12b,12c,12d]. The interview process was, in turn, supplemented with a questionaire on transition that was sent to 277 Fortune 500 companies [12b]. The concepts presented in this paper and the beginning of the planning for the resolution of problems of NSTS are based on this research.

PLANNING THE CHANGE

Strategy Development. The organization undergoing a major structural change should develop a strategy to help facilitate the change. In developing a strategy, we contend that the planners must understand the considerations and actions for each of the four phases of the transition life cycle. The Creativity Phase is essentially the time

period where the transition strategy is created. In order to facilitate the creation of the strategy a four step analysis of the transition has been developed by the authors (Table 2). Consideration of this basic strategic guideline will lend invaluable assistance for the development of such a strategy and certainly is an early step in the problem solving process. As an implementation consideration, the Four Step Analysis was utilized in numerous industrial interviews and with NSTS at NASA. Furthermore, the analysis can be used as a guideline to help in determining courses of action as the life cycle matures.

Most of our experience, including that with NASA and with the industrial interviews, lies within the Creativity Phase. As this phase is that which determines the transition strategy, this paper concentrates on this phase of the transition life cycle and the four step analysis. Furthermore, the four step analysis should be used in each of the remaining three phases. The analysis will be beneficial in the fact that it, by design, can be used as a monitoring tool.

Each of the questions in the four step analysis should be answered in a rigorous manner. By answering Question One, the organization needs to determine its strengths, its weaknesses and its current status. We define the status in terms of the organization's goals, objectives, and value system.

From the industrial interviews and NSTS it was found that management has a tendency to concentrate on "Where do we want to be?". The answer to this question is obviously related to the future state of the organization. The answer should determine proposed goals, objectives, and a value system for the future state. Additionally, in

TABLE 2. FOUR STEP ANALYSIS OF THE TRANSITION MANAGEMENT

The following are the questions to be addressed and some of the issues to consider and gain understanding of at each step of the transition management.

1. <u>WHERE ARE WE NOW?</u>

2. <u>WHERE DO WE WANT TO BE?</u>

   Both Question 1 and Question 2 should be addressed in terms of:

   o The internal position of the organization with respect to the technical, political, cultural, managerial and financial situations.
   o The external position of the organization with respect to its competitors, other organizations and market conditions.
   o Performing systematic environmental analysis of the internal and external position of the organization.
   o The organization's long and short term goals, targets and strategies.
   o Establishing the expectations of and from the organization by the employees, stockholders, community and others.

3. <u>HOW DO WE GET THERE?</u>

   The answer to this question necessitates:
   o Developing a complete definition and understanding of the change.
   o Considering all options of the desired change strategy.
   o Definition of the level of involvement and degree of commitment of all human and nonhuman resources.
   o Establishing the expected level of change in the technical, political, cultural, managerial and financial aspects of the organization.

4. <u>HOW BADLY DO WE WANT TO GET THERE?</u>

   The answer to this question is a function of:
   o The uncertainty in the technical, political, cultural, managerial and financial aspects of the organization.
   o The time frame available for the change.
   o The level of perceived need for the change at different levels of the organization.
   o The availability of human and nonhuman resources for the change.
   o The level of commitment to the change at different levels of the organization.

order for the new state to be operational, one of the objectives should include considerations for timely performance of the system.

Before addressing the third question, the necessity of answering all four of the questions should be stressed. In an attempt to find a quick response for the transition, management may only find a solution primarily concerned with this question. Many different models have been suggested for transitions by people in industry. Therefore, if "How do we get there?" is answered too hastily, the model used for the transition may be inappropriate; i.e. a very useful model in one situation may be very detrimental in another situation. Further, a complete understanding of the four phases of the transition life cycle facilitates a better comprehension of how we propose a transition to occur.

Finally, "How badly do we want to get there?" is important because the answer to this question directly affects the amount of perturbation the organization will undergo as well as the amount of resources to be expended for the proposed change. Although the desire to change may be well defined in an organization, the extent of the desire is generally a relative phenomena which needs to be established. Also, with the consideration of the first three questions of the four step analysis, the answer to Question Four will enable management to select a model for the management of the transition. Again, the answer to the fourth question is situation dependent.

In order to address the problem of transition management for any organization, this four step analysis forms the foundation on which an understanding of the system can be built, developed, and implemented. Before an attempt is made to develop an approach for the transition

management of any organization, it will be helpful to understand the management system before and after the transition. The understanding of the system, while clarifying some of the questions of Table 2, will substantially help in the planning and implementation of the transformation procedure. To help illustrate this concept see Figure 3. The four step analysis forms, in the Creativity Phase, a rough but thorough idea of how the transition is to occur. As the life cycle matures and as changes are made, the rough edges will be smoothed--this is facilitated by periodically completing a four step analysis in each of the subsequent phases.

CREATIVITY PHASE

The information presented in the following sections describes, in general terms, the R&D and Operations environments. The information is, in essence, an application of our strategy to the R&D to operations transition. It serves, therefore, as an example of the problem solving structure. In addition, it helps to illustrate the depth required in the analysis. While not necessarily complete, the information presented is intended to paint a picture of the two environments. Although specific organizations may differ from the descriptions presented, the general sense of the descriptions is still applicable to help define the boundaries of the transition problem. The descriptions also serve to emphasize the magnitude of an R&D to Operations transition.

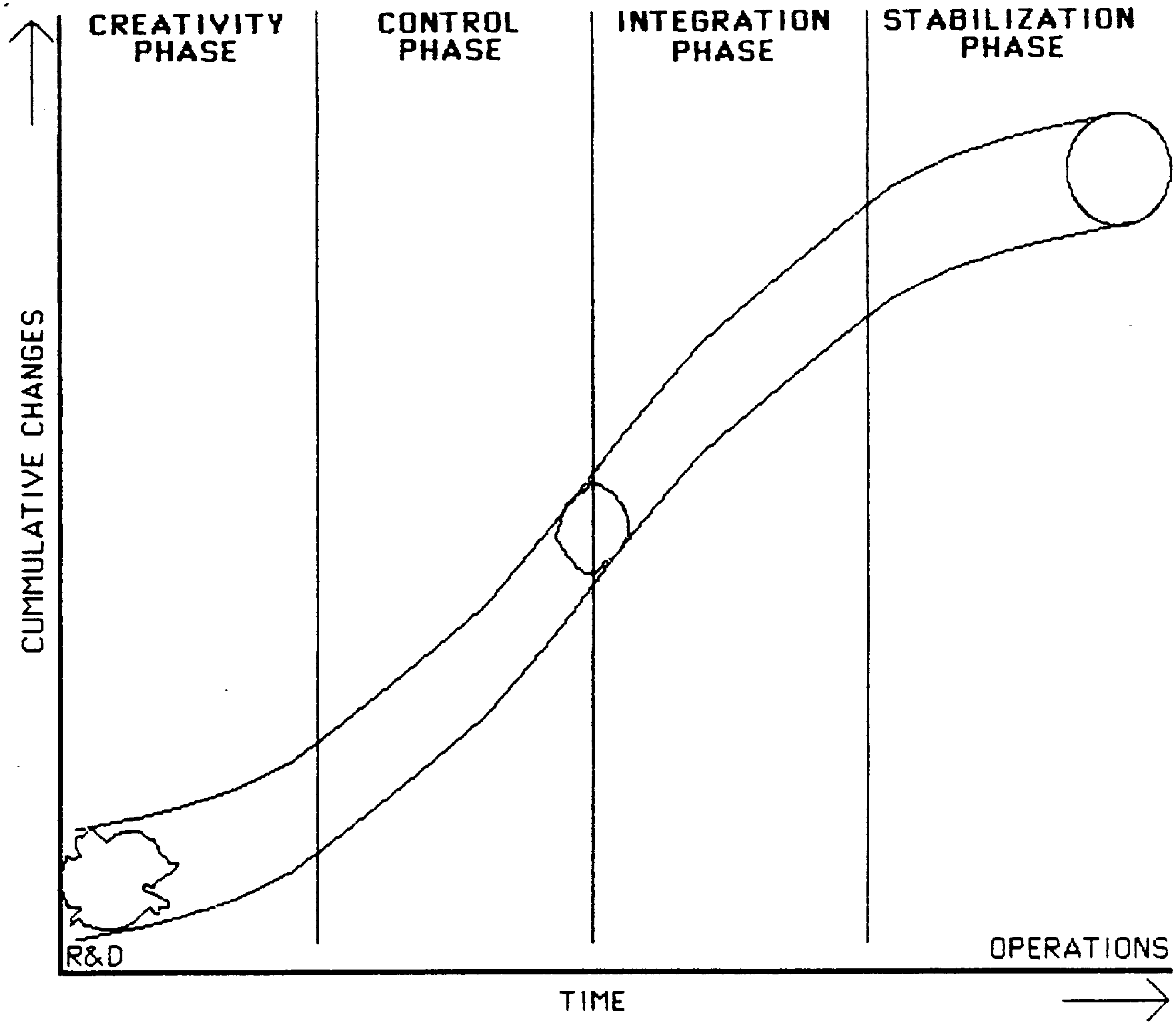

FIGURE 3. UNDERSTANDING OF THE TRANSITION MANAGEMENT AS A FUNCTION OF TIME.

STEP 1: WHERE ARE WE NOW?

The trivial answer to "Where are we now?" is "We are a Research and Development organization." However, there must be an in-depth understanding of the R&D system. This section intends to develop this "in-depth" understanding through the analysis of the environment, function, and means of controlling the organization.

Environment. The key to a successful R&D organization is the very presence of the atmosphere of creativity [3]. The approaches taken and followed by the management have a tremendous potential to increase the morale and productivity of the organization. One of the more important approaches in effective R&D management is the judicious balancing of the behavioral and technoeconomic considerations. The approach calls for a collaborative, not a competitive, work environment and flexibility in the operating procedures. The management job, while maintaining the economic viability of the organization, is to provide the following features for establishing a creative climate [14]:

- Autonomy and challenge to the individuals and groups;
- Responsiveness to individual ideas;
- Ability to foster curiosity and wonderment;
- Tolerance of differences of ideas; and
- Inter and intra organizational communication.

The extent to which these features are to be provided or made available to a research group depends upon the type of the work involved. For example, the creativity of an undirected research group following an offensive/defensive strategy should itself be "undirected," since ideally its desired output is a continued but unspecified flow of novel inventive ideas [14,19]. Much of the work in this category involves conceptualization and theoretical investigation

[5]. This intellectually demanding activity performed mostly by highly mature scientists demands low bureaucratic activity and a more supportive work environment. On the other hand, the success of the company following an applications engineering strategy is dependent upon the continued ability of its development engineers to provide creative solutions to particular user problems in a timely manner [19]. The two examples in a way are two extremes in an R&D environment. In most situations, it is generally a mixture of complete autonomy on some subjects and considerable control on the others. Whatever the situation, it is important to realize that the very survival of an R&D organization is dependent upon its ability to be creative and innovative, and this objective may not be sacrificed for any short term goals.

Function. The function of an effective R&D management is not only that of usual short term planning of uncertainties and daily routines, but is also that of planning for the future growth and direction of the organization [15]. A representative research and development organization may have one or more of the following primary objectives along with some secondary objectives as well [6,19]:

- Discovering and furthering knowledge;
- Developing new products;
- Improving the existing products;
- Finding new uses for the existing products;
- Improving production processes;
- Finding potential uses for by-products or waste products generated by the present production system;
- Providing technical services to the functional departments in the organization;
- Analyzing and studying competitors.

How some of these functions and objectives are realized is the responsibility of the R&D management. Quite often it is possible that some objectives may have conflicting requirements. Under such circumstances, it is again the responsibility of the management to find a compromise formula which does not sacrifice the organizational interests. The important aspect while making such decisions is to keep in mind that the very survival of the R&D organization is dependent upon the ability of its members to foster innovation. Any organizational policy which curbs the innovative environment will eventually result in substandard performance by the organization. Indeed the organizational attributes do not produce creativity, but are aimed at motivating the individuals to be creative [21].

Besides the proper environment, the organization requires the right kind of people to do the job [11]. It demands people who can work independently and develop innovative ideas in an often undirected research oriented organization. However, if the research activity is of a directed nature, then the pressure caused by the demand warrants hiring people who have the capability of working under pressure. In simple terms, the R&D organization requires hiring people who can perform the work expected of them. Furthermore, there is a requirement of creating a forum such that all of the top researchers in the organization can effectively communicate with each other and with the management of the organization. The proper interface will help in a better utilization of the resources and a close conformation to the corporate management strategy [11].

The next issue is that of behavioral and technoeconomic considerations for highly motivated researchers. Inherently the R&D

people require a collaborative environment in which the decision making process is shared. The day-to-day decision making is also mostly delegated, and operating procedures are flexible to support and encourage the ingenuity of the researchers. The interaction between superiors and subordinates, being informal, is usually low-keyed. One of the watchdogs for the R&D people, however, is their inherent nature of being perfectionists. At times the cost of perfection goes beyond the limits of the control system. In such situations a compromise which does not discourage the researchers is necessary.

Implementation and Control. A major difficulty in R&D management arises on the economic side of the picture. An environment which fosters innovation seems mandatory for a research and development organization. Unfortunately, there is a high cost--mainly arising from salaries--associated with obtaining this environment. Given a perfect arrangement an organization is in a good position to flourish in the long run. However, every organization requires economic viability.
Moreover, the lack of historical data to evaluate the alternatives makes the problem of economic analysis more difficult. Any activity directed toward control could actually be curbing innovation and should therefore be cautiously planned and monitored. Thus, the solution to this delicate situation remains. The one phrase answer for the solution is, "Balancing of behavioral and technoeconomic considerations" [19]. The responsibility of R&D management is to perform that balancing act without hindering the creativity.

Application to NASA:

In order to help NASA answer the first question, our research team conducted a thorough demographic study [12a,12b,12c,12d]. It was found that NASA's

- o average technical employee is 43 years old;
- o employees are mostly engineers;
- o work force has 27% of the employees with a master's degree or higher;
- o average employee service length is 16.4 years;
- o average employee starting age is in the late 20's;
- o workforce is experienced with most experience in R/D programs;
- o workforce has had significant decreases in manpower; and
- o workforce reduction is due to hiring freezes, transfers to other programs, and employee pursuit of higher wages.

In addition to the demographic study it was found that each Shuttle flight is unique thus requiring unique preparations. In this respect, NSTS is essentially working as an R&D organization with each of the flights acting as different projects.

STEP 2: WHERE DO WE WANT TO BE?

Given the foregoing examination of the R&D environment, the next question, "Where do we want to be?" deserves attention. This section examines the answer to this question in a form similar to that used in the discussion of the R&D management section.

Environment. The important factor in the smooth functioning of Operations management is the presence of a well structured organization. The leadership of the organization is instrumental in providing this function. Leadership is also responsible for creating the operational objectives and ensuring smooth work flow. The

principal function of the leadership of Operations management is in its responsibility to maintain the future direction for the economic growth of the organization. In other words, leadership is responsible for what the organization must do to remain economically viable. In the process of maintaining economic viability, a participative environment should exist in order to gain the support and commitment of the employees. In addition, effective Operations management requires:

- A healthy and competitive work environment;
- A judicious reward and incentive system;
- Independence in decision making in congruence with the organizational guidelines;
- Formality in the procedures;
- Flexibility towards change.

Function. The function of Operations management is to provide goods and services to fulfill an anticipated demand on a routine and timely basis. Due to the quantitative nature of the function, the performance of the Operations management can be evaluated on the basis of physical and economic considerations [8,16]. The criteria of physical performances are those related to the quantity and the quality of the work produced. Whereas those related to the economic considerations are the measures of how effectively the resources were utilized to achieve the overall objectives of the organization. The economic considerations include timing and location of the production, along with the equipment, material, energy and labor utilization. All of these considerations must be converted to common economic terms in order to evaluate the contribution of the resources toward the overall objectives of the organization.

The objectives of the Operations are well defined and, for the most part, are quantifiable, which simplifies the evaluation. Similarly, the performance is also measurable in terms of how well the management handles the conversion process that transform the inputs into the desired outputs. This implies that the working model and performance criteria of the Operations management are well established. Moreover, because the structure which forms the basis of management control is well established, implementation of the working philosophy of Operations management is facilitated.

Implementation and Control. The important factor in the smooth functioning of Operations management is the presence of a well structured organization. The leadership of the organization is instrumental in providing this function. Leadership is also responsible for creating the operational objectives and ensuring smooth work flow. The principal function of the leadership of Operations management is in its responsibility to maintain the future direction for the economic growth of the organization. In other words, leadership is responsible for what the organization must do to remain economically viable. In the process of maintaining economic viability, a participative environment should exist in order to gain the support and commitment of the employees. In addition, effective Operations management requires:

- A healthy and competitive work environment;
- A judicious reward and incentive system;
- Independence in decision making in congruence with the organizational guidelines;
- Formality in the procedures;
- Flexibility towards change.

__Characteristics of Operations Management.__ The evaluation of Operations management is much easier as compared to that of R&D management. Most of the variables in Operations management are quantitative and therefore can be readily measured and appraised. The leadership function of planning, as in any other management situation, is very important in the operational environment. Unlike R&D, where most of the future direction of the organization is prescribed by the scientists and researchers working within the corporate philosophy, Operations management has the primary responsibility for this function. However, the planning function of "What has to be done," performed by the top management may not be interpreted to imply non-participation by the employees. The employees participation is very important in "How it could be done," primarily because they have the proper expertise and definite interests in the area. The absence of participation in the latter situation can very likely result in low morale, lack of commitment to the work, and eventually lower productivity. The other requirement in the smooth functioning of Operations management is the presence of well defined structure. These two requirements may seem to be at odds with each other--indeed there is a delicate relationship separating them. There is a definite need to have established operating units with defined functional boundaries. Within the boundaries there is tremendous room for employee participation which will enhance the smooth working of the operating unit. Further, there is need for the cooperation and participation between the operating units. Such linkages are important from macro perspective and they eventually reduce the need for a strict control system, thereby improving productivity. The organizational

structure must provide for such defined channels by which such cooperation can be achieved.

Table 3 provides a pair wise comparison of thirteen elements between the two management systems--R&D and Operations. The comparison of these elements, along with the consideration of the first two questions in Table 2, will create a strong understanding of the organization before and after the change. This strong understanding is beneficial in making a smooth transition.

<u>Application to NASA:</u>

NSTS needs to determine its goals and objectives and to have them accepted and understood throughout its workforce. Without goals and objectives, the organization is in danger of becoming a directionless program. In addition, some effort must be expended to get the people to sign on to the program. Goals and objectives provide purpose. Without purpose there is nothing for the members of the organization to sign on to, commit to, or to work for.

As of now, it is not apparent that a thorough set of goals and objectives exist at the NSTS. Related to this question is the question of what is hoped to be gained by the utilization of the shuttle resource. NASA does know that some of the strategies desired consist of flying as often as possible and flying as safely as possible. Whatever the overall strategy, goals, and objectives may be, it is necessary that they be well defined if the program does not wish to lose direction.

Further, in order to become operational, NASA must realize that some of their hiring and training practices must change. As pointed

TABLE 3. CHARACTERISTICS CHART OF R&D vs. OPERATIONAL MANAGEMENT

ELEMENTS OF ORGANIZATION	R&D MANAGEMENT	OPERATIONAL MANAGEMENT
1.OBJECTIVES AND TARGETS	* Discovering and furthering knowledge under corporate planning. * Provide technical services to functional departments. * Objectives are generally defined as opposed to means. * Looking for significant breakthroughs.	* Fullfilment of well defined purpose which are reason for its creation and existance. * Achievement of the economic balance between demand and resources. * Looking for minor changes in incremental fashion. * Concerned about stability of the system.
2.ORGANIZ-ATIONAL STRUCTURE	* Fragmented: Divisional, Functional, and Flexible. * Allows easy transfer of info-rmation and personnel (10).	* Hierarchical. * Specialized, and clearly defined tasks.
3.SYSTEM HIERARCH-IES	* Authority is based upon the technical expertise (7). * Commitment to the task is negotiated.	* Authority is based upon the organizational position (7). * Responsibilities are mostly accepted.
4.LEADERSHIP BEHAVIOR	* Responsible to provide input to the strategic planning on a proactive basis, and not solely reactively (6). * Provide proper career development programs for scientists and researchers. * Provide behavioral and tech-nical support at all levels.	* Provide motivation and the targets for achievement. * Unity of command. * Provide technical guidance on how and what is to be performed.
5.SYSTEM MANAGEMENT	* Easy access to resources. * No short term work pressures. * Corporate strategy must be driven without long formal process. * Self directed and mostly responsible for own work. * Open discussions. * Friendly competition. * Decentralized power base.	* Defined/restricted access to resources. * Institutional organizational channels. * R&D and ventures must be tied-in with other growth oriented activities. * Worker is a part of the whole; guidelines are there-fore necessary for coordinat-ing activities. * More focused power base.
6.PERFOR-MANCE CRITERIA	* Long-term, risk / reward oriented on new businesses. * Encourages the strategic innovation.	* Short-term, result oriented on existing businesses. * Short-term evaluation programs are used where external factors are easily predictable.

EMENTS OF RGANIZATION	R&D MANAGEMENT	OPERATIONAL MANAGEMENT
.REWARD SYSTEM	* Recognition, status, and more complex assignments(10).	* Financial and hierarchical progression (10).
.COMMUN-ICATION SYSTEM	* Across the major operating units (10). * Mostly informal networks of communication. * Communication at low level.	* Within major operating unit. * Lateral communication is too specialized and at high levels. * Formal communication network.
.INFORM-ATION SYSTEM	* Forward and outward oriented towards future needs. * Large amounts of the data received and processed.	* Highly structured towards the need of existing businesses (10). * Minimum amount of inform-ation is handled.
0.FLEX-IBILITY	* Long-term commitment to the projects. * Flexible control of people. * Mostly undirected activity. * Room for creativity.	* Short-term schedule of the changes. * Structured job description. * Limited undirected activity. * Flexibility to allow room for productivity.
1.WORK EN-VIRONMENT	* Friendly, with respect for peers. * Working with, instead of working for. * Intellectual freedom. * Flexibility to some extent in organizational rules.	* Competitive and target oriented. * Structured work schedules. * Conformance to organizational rules. * Formal work environment.
2.CULTURAL CLIMATE	* Motivation by peer recognit-ion and job satisfaction(20). * Internalized standards, as a result of extensive training. * Collegial approval sought; often based upon long run quality (7).	* Competitive and financially oriented. * Motivated by rewards, job satisfaction, recognition of work and authority. * Established norms for the overall organizational rationality; often based on short term efficiency. * High work pressure.
3.POLITICAL CLIMATE	* Loyal to profession and organization; seek collegial approval and external recognition; identify with goals, values and incentives of profession (9). * Referent, information and expertise is the source of power for people with high maturity.	* Loyal to organization; seek super-ordinate approval and recognition; identify with goals, values and incentives of organization. * Organizational participants are in contest for resources and their control.

out by the demographic study, NASA has had recent workforce reduction. Also, the employees in the workforce are mainly practiced in R&D methods. In addition, the people who do R&D and the people who do operations are two different sets of people. The people who do well in managing transition programs may well be a different set yet. The usual programs for employee control and change such as attrition, turnover, and rehires will be of some use here. However, the bulk of the employees will have to be trained in the new ways. This training is going to be perhaps the major component of the transition program.

STEP 3: HOW DO WE GET THERE?

When applied to the Creativity Phase, the answer to "How Do We Get There?" is reached by a consummate understanding of the four step analysis, the transition life cycle, and the transition curve. Further, the answer to this question is in fact the essence of this paper.

The basic strategy of the concepts we have been presenting herein is to overlay or integrate the four step analysis on the transition life cycle which has, in turn, been integrated into the transition curve. See Figure 4. While the fit between these three pieces may not always be exact, at the very least, a more complete picture of a transition strategy is determined. Further, it is the transition managers, along with all people involved in the change process, that are the missing pieces. Therefore, some changes must be made to ensure that all people necessary get committed to the transition to facilitate a smooth transitional program.

When applied to later phases in the life cycle of the transition,

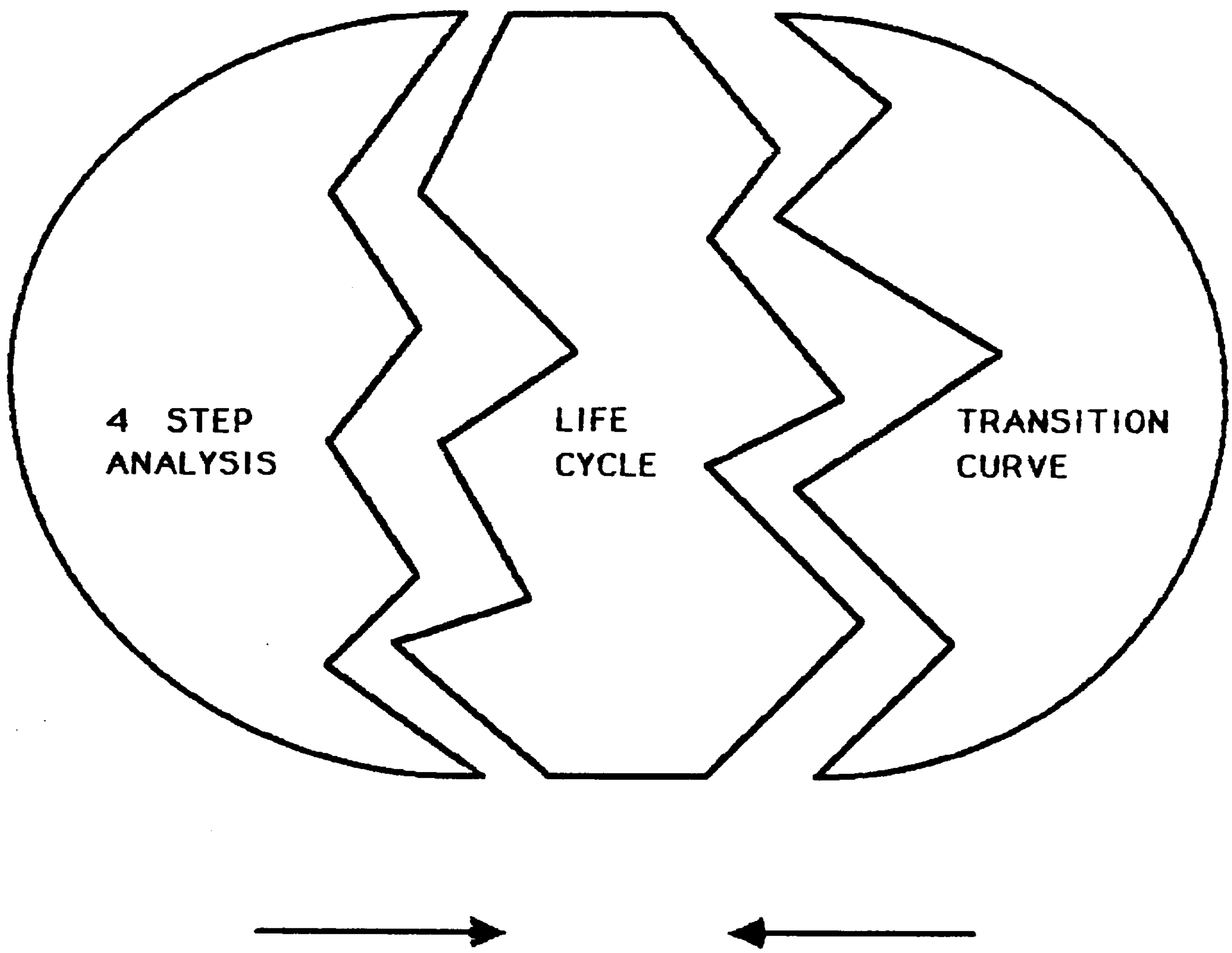

FIGURE 4: TRANSITION MANAGEMENT CONCEPT

the answer to this question would be found, again, after considering the present state (where the organization is in the transition), the future state (including new, or changed, objectives and goals), and the activities and objectives of the different phases of the transition life cycle until the Stabilization Phase is completed.

<u>STEP 4: HOW BADLY DO WE WANT TO GET THERE?</u>

Before a model is chosen for the transition, the organization should answer the final question of the Four Step Analysis. The answers to this question decides the amount of resources to be expended and the amount of disturbance in the organization caused by the transition. "How badly do we want to get there?" is also vital in the planning process as its answer will help to uncover various uncertainties the organization will face. These uncertainties are in the technical, political, cultural, managerial, and economic facets of the organization.

Noel M. Tichy, in "Managing Strategic Change" [22], discusses the Technical, Political and Cultural (T/P/C) dimensions in the management of change. He states that whenever a change is made in the organization, the technical, political and cultural aspects of the organization are bound to be affected and should therefore be considered. He also provides a diagnostic analysis to determine the possible need for change in each of the three dimensions. However, the book fails to suggest a plan of action given the results of the diagnostic analysis. When applying his work to transition management, Tichy very nicely provides three dimensions of concern, but the absence of a guiding strategy still remains a missing link. Figure 5 addresses

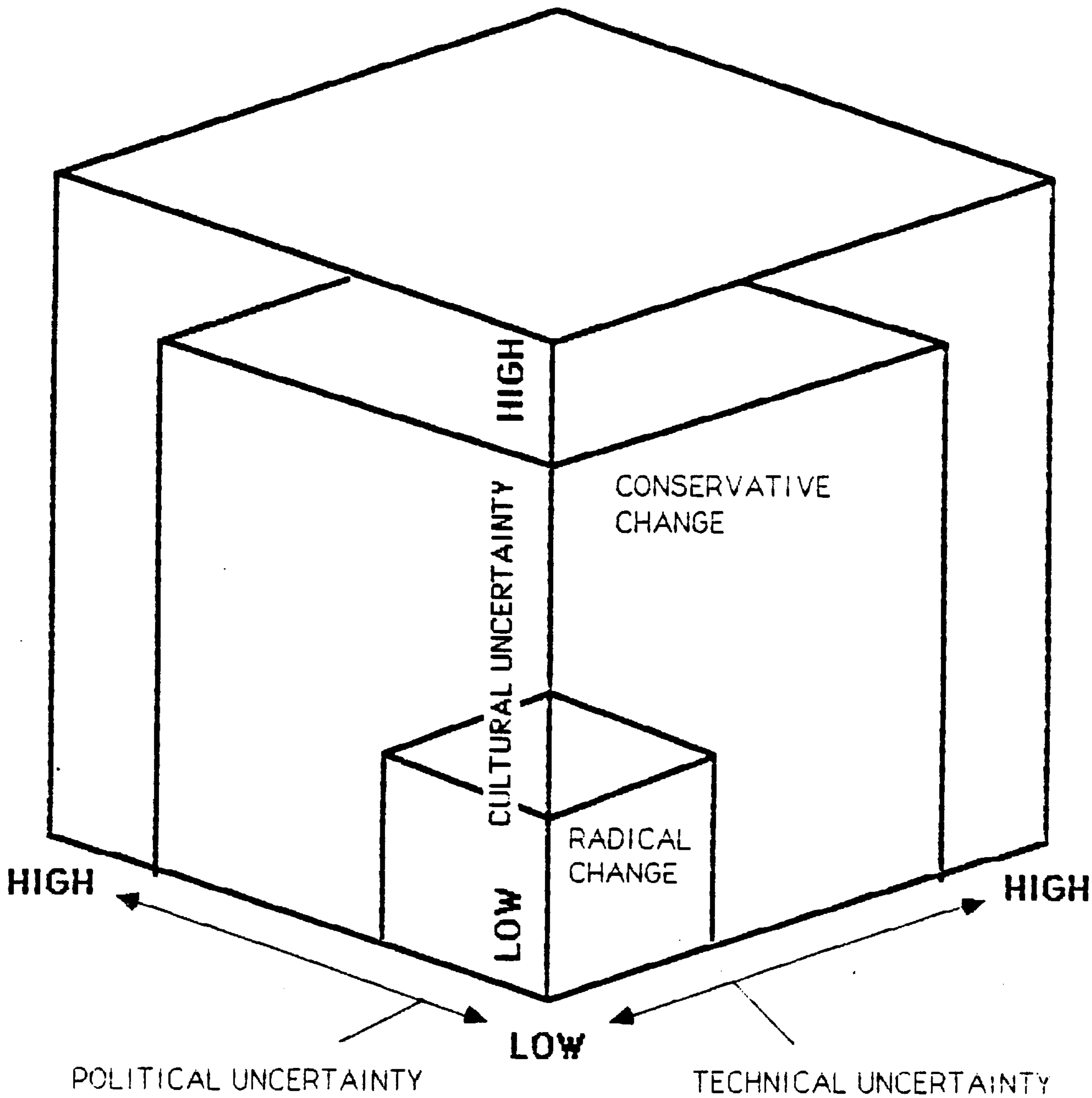

FIGURE 5. PLANNED CHANGE AS A FUNCTION OF UNCERTAINTY

this issue of the transition management and suggests a latitude of choices ranging from a radical change to a conservative change. The figure suggests that a radical change is feasible under low areas of technical, political and cultural uncertainty. Furthermore, a conservative choice is preferred whenever one or more dimensions have a relatively higher degree of uncertainty. In the intermediate range of T/P/C uncertainty, a combination of the two extremes--radical and conservative--may be used. This combination will depend upon, among other factors, the organizational culture, the market position, and the level of T/P/C uncertainty.

There have been many models developed which consider different types of transition management strategies. In a previous manuscript [13], Hunsucker, Law and Sitton have described several of these strategies. Some of these strategies are listed in Table 4. For a more thorough description of these models we refer the reader to the earlier manuscript [13]. The following two subsections discuss the strategies listed in Table 4. We must stress that the use of the models presented relies on the varying amounts of uncertainties and factors which were discovered through the consideration and answer of the final question in the Four Step Analysis.

<u>Size of the Transition Increment.</u> The first of the transition management strategies to consider is the size of the transition increment. The increment reflects the magnitude of the changes the organization undergoes as the transition moves through its life cycle. The Dissipative Change Model (DCM), corresponding to a large incremental magnitude, and the Logical Increment Model (LI),

TABLE 4. TRANSITION MANAGEMENT MODELS

* SIZE OF THE TRANSITION INCREMENT
    - o LOGICAL INCREMENTALISM (LI) -- SMALL INCREMENT
    - o DISSIPATIVE CHANGE MODEL (DCM) -- LARGE INCREMENT
* SHAPE OF THE TRANSITION MANAGEMENT STRUCTURE
    - o MANAGERIAL DUAL ROLE (MDR)
    - o PARALLEL TRACK MANAGEMENT (PTM)
    - o HAND OVER TEAM (HOT)

corresponding to a relatively small incremental magnitude, are two extremes in the size of the transition increment. The transition should be made in increments, within the LI and DCM extremes, that reflect the different levels of uncertainty within the organization. Another important consideration in model selection is time. Model choice should be a function of the period in time the model is to be used, the length of time required by the transition, and the amount of time available before the new state must be in place.

The Dissipative Change Model can be used when a seemingly instantaneous change, which is large in magnitude, is necessary [2]. The position in which an organization has to suddenly change its line of product based upon market change or technical breakthrough is a candidate illustration for the application of DCM. One such application of DCM occurred when a large corporation developed a line of stand-alone computers [2]. However, if DCM is used during high levels of uncertainty, the organization exposes itself to high risks of instability. Therefore, as the uncertainty of the situation and level of resource commitment increases, the need for a more deliberate process becomes important. We contend a comprehensive evaluation phase, if possible, can be an appropriate aid in acheiving a full-fledged organizational commitment. This evaluation phase requires the analyzation of the proposed transition and subsequently planning the change to occur in smaller incremental steps.

The organization in the consideration of making a more deliberate transition may make use of the Logical Increment Model in making a more deliberate transition. LI provides an evolutionary process for making changes and proposes that such changes be made in small increments

[17]. A major advantage of LI is that it allows for easy modification of the transition management as the change matures. This advantage aids in the development of cohesion, morale and consensus throughout the exployees towards the transition.

<u>Shape of the Transition Management Structure.</u> The shape of the transition management structure can also facilitate a smooth transition. Three different ways of managing the transition have been researched. One method of managing transition consists of utilizing the current management to manage the change--Managerial Dual Role. Two methods involve the creation of a transition committee to control the transition--Parallel Track Method and Hand Over Team.

A shortage of manpower or the presence of an environment not conducive to a team approach are cases in which the transition management should be controlled by the current management. Under Managerial Dual Role (MDR) the current management with the same structure handles the transition management along with the normal business and thus is able to overcome the obstacles of manpower and environment. One such instance of MDR occurred when a large engineering and construction company used managers to handle a quality improvement program as they concurrently handled normal operations [12]. One advantage of MDR is that it allows employee tension to be mitigated since there is only one management system instead of two separate ones. The use of one management system may reduce employee stress because employees need not worry about loyalty to different management systems. Another advantage of MDR arises when there is a high degree of risk in managerial and economic uncertainty. MDR allows

the transition to proceed slowly until the uncertainties are successfully resolved [13].

When there is an urgency in the need and desire to make the change, the use of a parallel management team concept can expedite the process of the change. The Parallel Track Model (PTM) provides a framework for such a parallel management system [1]. PTM allows for two management structures to function simultaneously during the transition: one to manage normal business and one to manage the transition. Some companies which used a parallel track management system in change programs are a public transit company, a communications company, and a public utilities company [12]. Under PTM, an employee can be a member of both the present and transition management teams. This joint membership can be very helpful for the cohesiveness of the organization. But, unfortunately, it can also result in the diversification of individual and group concentration. Therefore, in order to avoid possible diversification, another approach of project or transfer team can be adapted. This method is the Hand Over Team approach.

Similar to PTM, the Hand Over Team (HOT) approach develops a separate team to manage transition. Organizations which emphasized the use of a hand-over system are an electronics assembly plant and a medical technology firm which designs and manufactures its products [12]. The major difference between PTM and HOT is that while PTM may have managers dealing with transition and normal (routine) activities, HOT managers concentrate little, if any, on routine matters. The Hand Over Team starts out small with top level managers. As the transition progresses, more and more people are added to the Hand Over Team until

it emerges as the management for the desired system (i.e. Operations). Because top level managers are enlisted initially, a high level of commitment towards transition is introduced at the HOT's inception. This high level of involvement can allow the transition to happen relatively rapidly.

As can be seen, these three styles, MDR, PTM, and HOT, represent a continuum of transition management involvement with the normal business of the company. MDR has maximum involvement of the transition managers with the usual business. PTM has medium involvement. HOT has little, if any, involvement. The amount of managerial resources available to do both jobs, transition and normal business, is an important consideration in the choice of a model.

Suggestions for Model Selections. Figures 6 and 7 present a more descriptive framework for the selection of a particular model. Tichy's diagnostic analysis (T/P/C) forms the basis for the type of change; i.e. radical or conservative. Furthermore, the organization faces economic and managerial uncertainties. For example, if the T/P/C uncertainties are low, and the economic and managerial uncertainties are also low, then, as presented by Figure 7, the transition from R&D to Operations can take place using the Dissipative Change Model. Since the organization has a large amount of control over all uncertainties, the change can happen rapidly. However, if the economic and/or managerial uncertainty is relatively high (T/P/C uncertainties remaining low) the Dissipative Change Model can be utilized with the help of the Managerial Dual Role Model. MDR allows for the organization to handle the managerial and/or economic uncertainties

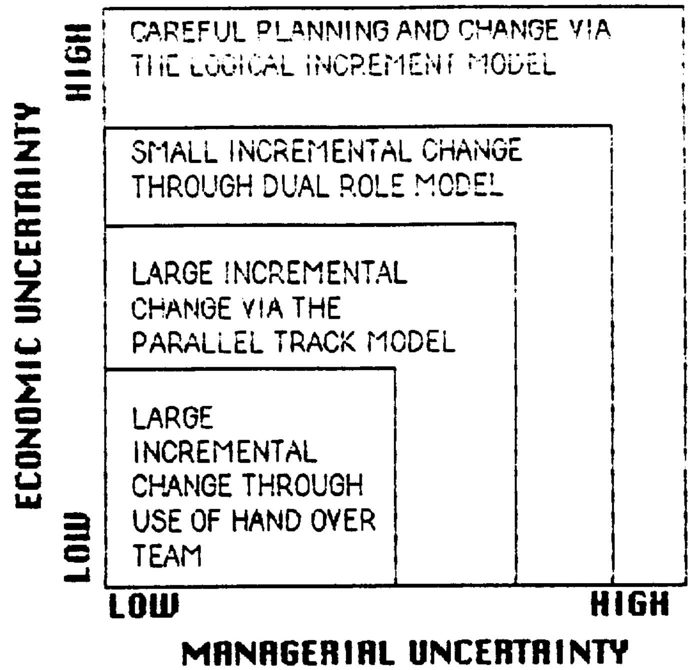

FIGURE 6. MODELS FOR CONSERVATIVE CHANGE

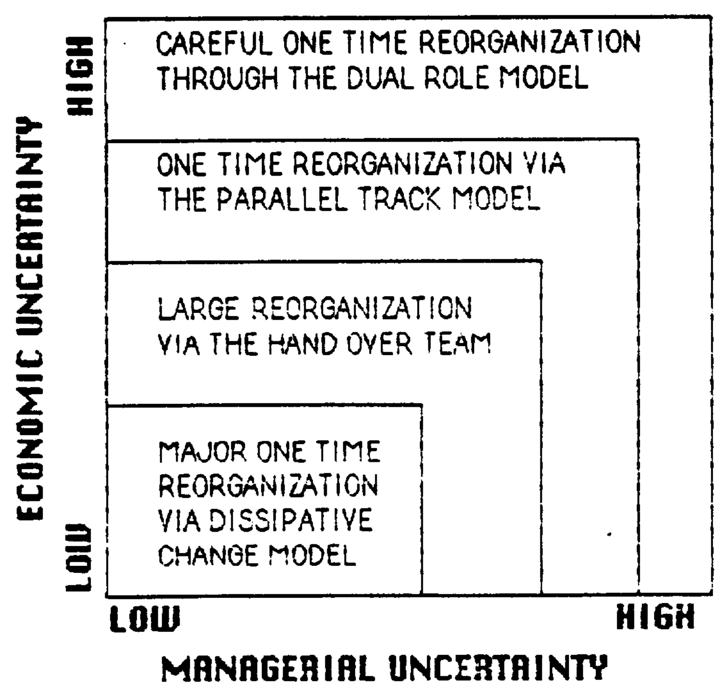

FIGURE 7. MODELS FOR RADICAL CHANGE

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which are prevalent.

Although Figures 5, 6 and 7 lend guidance for the selection of the transition management system we do not contend that the organization will not successfully make the transition if it does not select the model from this framework. The organization may or may not suffer detrimental effects if a model is chosen without consideration of the selection process embodied in these figures. However, for various reasons, the consideration of these factors in the choice of a model can help to reduce stress and improve the chance of success. Further, once a model is chosen and the transition path is determined, the Creativity Phase, associated with the creation of the mechanism for change, has ended. The success or failure of the transition will rely on the ability of the planners and managers to guide the organization throughout the remaining phases in the transition life cycle.

Application to NASA:

Most of the managers for NSTS are engineers. As a rule, engineers are relatively comfortable with the technical aspects of a project. However, for a transition to occur, the cultural and political aspects must be considered as well. To this end, it is not clear that NASA understands the significant cultural difference between R&D and operations. As an example of this difference, the motivation for "doing good" work is extremely different in these two environments.

So for NASA, the cultural and political aspects of a major transition perhaps provide the most difficulty. The managers will simply be uncomfortable with dealing with these two and may therefore tend to ignore them. This could of course prove to be a major

stumbling block to a successful transition. Consequently, precautions should be made at all times to consider and handle these factors.

Because there is a high level of political and cultural uncertainty, the planned change we insist, should be a conservative one. Consequently, the size of the transition increment NSTS should use in its proposed change should be small; i.e. Logical Incrementalism.

Further, NSTS will have to decide what structure it wishes to use to manage transition. One thing is reasonably clear: the people who manage the transition should have a major stake in the organization after the transition. This concept is related to the idea that if a proposal team is successful in their bid for a contract, then they should have significant responsibility in the management of the contract. This should help to insure that the transition is carefully thought out and implemented.

More than likely, a transition team would have to have representation from all the major centers and program elements. In addition, the leadership would have to come from headquarters.

CONSIDERATIONS FOR THE LIFE CYCLE MATURATION

As previously stated, this paper concentrates on the four phases of the transition life cycle and the four step analysis and how each are used to begin planning a transition. Upon determining the method by which the transition is to occur, that portion of the Creativity Phase--dealing with the creation of a mechanism for making the change--is completed. Similarly, the four step analysis as applied to the Creativity Phase is completed once the method of change is determined.

However, as this is just the planning stage, we offer a warning. As we have suggested, there are three additional stages in the transition life cycle. The transition management team must fully be aware of the objectives and actions to be taken during these phases. Further, the transition program itself goes through changes. Due to the variation in the dynamics of the two environments, the organization is susceptible to continual transformation until the desired environment is reached. Thus, where one concentrates on the proposed transition method, conceivably it becomes apparent that the study of change is an ongoing one. Therefore, by consideration of the four step analysis in each of the three remaining phases of the life cycle of transition, management has a way of monitoring the change and can thus determine proper actions to take as the life cycle matures.

CONCLUSION

The management of any organization is vested with a continued responsibility of monitoring the dynamics of the organization and keeping the organization current and competitive. When an organization wishes to move from an R&D environment to one of Operations, a shift of this magnitude warrants the development of a strategy to manage this transition. The consideration of the Four Step Analysis as it applies to the four phases of the transition life cycle provides a structure in the development of this strategy.

In the R&D to Operations shift, the diversity of the two systems is so remarkable that a consummate understanding of the two congregates is necessary before planning the transformation. This consummate understanding is reached by answering the first two questions of the

Four Step Analysis and presenting, if you will, a side by side comparison of the two systems.

Once the organization understands the current and future states it can concentrate on the planning of the movement. This planning process is facilitated through the answering of the remaining two questions of the Four Step Analysis.

Finally, there are several change models available in the literature. The model chosen for making the transition is selected, upon consideration of the final questions of the analysis, as a function of the uncertainty in the technical, political, and cultural (T/P/C) dimensions of the organization; i.e. the model is situation unique. The model is also selected according to the level of managerial and economic uncertainty. In addition, change models may be accompanied by the formation of transition management structures. By utilizing management structures, the organization can let the current management system handle the change or create a transition committee to control the change.

This Four Step Analysis forms the major portion of the Creativity Phase of the life cycle. As the transition moves though the remaining three phases, the analysis must be repeated.

The concepts presented in this paper are certainly not a complete description of the change process, neither are they a "blueprint", which if followed, will guarantee success. They are, as they claim to be, a theoritical process useful in formalizing the initial planning stages of a transition. As such, they have been of value in assisting NASA in the initial strategic considerations of moving the shuttle program to a more operational nature.

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CHAPTER VI

AN ANALYSIS OF SPACE SHUTTLE SCHEDULING AND FLIGHT RATE PROBLEMS

APPENDICES

VI. AN ANALYSIS OF SPACE SHUTTLE SCHEDULING AND FLIGHT RATE PROBLEMS

1.0 INTRODUCTION

The primary focus of this chapter is to analyze the problem of space shuttle scheduling and flight rate capability of the NSTS program. The perception of some of the essential tools for effective operations and managerial planning is expected to help in developing the solution methodologies for such problems. To this end, several areas of production management have been studied in extensive detail in this chapter. The examples of the tools studied include the development and implementation of a branch and bound algorithm and a heuristic study of a flow shop with multiple processors. Furthermore, a flight rate capability analysis is also performed. The utilization of such tools is expected to be useful for better planning and predictability of the space shuttle program. The use of simulation and scheduling models will enhance the potential of the management to predict and control the system. Also, such tools are expected to be very effective in reducing the operational cost of the system. Tools such as these are not developed overnight. The theory required is on the forefront of scheduling research. While the tools, as presented here, may need additional refining, as the shuttle program matures, scheduling in the future of the shuttle will be based on

them. Given this, these tools form the fundamental building block on which shuttle scheduling will be based as the flight rate increases.

The scheduling problem of the space shuttle program and the flight rate capability of the NSTS program are briefly discussed here and a full description is contained in the ensuing appendices.

2.0 THE SCHEDULING PROBLEM

A schedule is a timetable for performing activities, utilizing resources, or allocating facilities. There are various measures of performance and solution procedures which can be used to address the problem. Basically, three types of decision making goals seem to be prevalent in scheduling. They are efficient utilization of resources, rapid response to demands and close conformance to prescribed deadlines. Frequently, an important measure of system performance such as job lateness, job waiting time, machine idle time, or average work-in-process is used in the literature on scheduling. The purpose of Appendix VI A of this chapter is first to signify the importance of the outcome of the scheduling decision. A brief description of the solution methodologies is later presented to show the direction of research in this important planning feature of the overall system. This exercise is expected to help better visualize the impact of such planning tools on the space shuttle

program.

Further, as has been discussed in the previous reports submitted to the NSTS, the processing of the space shuttles resembles that of a restricted flow shop with multiple processors. The first step in this research is to study the simplified problem of a flow shop with multiple processors. The basic model can then be extended for the constrained problem of space shuttle scheduling. There are numerous solution techniques that can be applied to the space shuttle scheduling problem. The choice can range from obtaining optimum or near optimum solutions from methodologies such as integer programming, mixed integer programming, linear programming, branch and bound algorithms, and simulation experimentations to heuristic procedures for single or multiple objectives. The optimal seeking techniques obviously have the advantage of arriving at an optimal solution, but the major drawback is in the computation time which makes them intractable for large problems. The choice of the solution approaches to solve the stated problem depends upon the size and complexity of the problem, and the desired accuracy of results.

Appendix VI B presents a branch and bound algorithm developed in this research for minimizing the makespan in a flow shop with multiple processors. Minimizing the makespan implies that the cost of schedule depends on how long the processing system is devoted to the entire set of jobs. The lower bounds developed in this research for the branch and

bound algorithm for minimizing makespan are generalizations of those used in the flow shop. The algorithm can also be used to optimize other measures of performance. The branch and bound algorithm seems to be very effective in solving problems of modest size for the makespan criteria. Besides, several elimination rules have been developed which increases the effectiveness of the algorithm to solve large problems.

Next, Appendix VI C presents the heuristic programming study of the makespan and mean flow time criteria for the flow shop with multiple processors. A static model of the flow shop with multiple processors is considered in which the queuing priorities are established dynamically. Nine priority rules, which have significance for the two criteria, have been studied in the research. The heuristic programming studies provide conclusive evidence of the superiority of the shortest processing time first priority rule for the mean flow time criteria. The heuristic programming study also provides general guidelines to establish priorities for the mean flow time and the makespan criteria.

3.0 FLIGHT RATE ANALYSIS

There are several factors which may be instrumental in causing any management to present higher or lower production, and/or flight rates. However, using unrealistic figures as production targets can be extremely dangerous for the smooth flow of the work in a production or operational environment.

Moreover, the selection of target production figures may also have a detrimental effect on the long range planning and objectives of the organization. Therefore, it is imperative that the management studies and uses the right production (or flight) rates before making any organizational commitment.

An analysis of the flight rate capability of the NSTS is presented in Appendix VI D. The basic premise in this study is to develop a methodology to predict the flight rate of the shuttle based on the assumption that JSC can support anything that KSC can fly. The historical processing times at KSC were used as a basis for the prediction model.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Part of the problem with considering shuttle scheduling is that there is no clear direction or goal concerning what to optimize at this stage of development of the shuttle program. As the program matures, it is hoped that management will become more familiar with the different objectives available for the optimization of the schedules. While such familiarity may not be required at this early stage of development of the operational program, it will be essential as the flight rate increases. One major use of the information presented on scheduling is to raise the level of awareness of managers concerning scheduling considerations. Another major use of the scheduling work is to continue to build the necessary foundation for the development of the

scheduling tools which will be required for the increased flight rate.

For these and other reasons, the work on scheduling needs to be continued as does the work on determining realistic flight rates. The scheduling work needs to continually be modified to form a closer model to the shuttle environment as the program matures. Specifically, work needs to be done in the areas of proportionate flow shops and on restricted flow shops. Concerning flight rate analysis, the statistical methodology needs to be updated and modified as the database grows with the number of successful flights.

APPENDIX VI A

THE FUNCTION OF PRODUCTION SCHEDULING

1.0 INTRODUCTION

A schedule is a timetable for performing activities, utilizing resources, or allocating facilities. The process of scheduling can be thought of as the implementation phase of production planning, and as a continued activity in the life of production systems. The purpose of scheduling is to disaggregate the general production plan into the time phased weekly, daily, or hourly activities. In other words, to specify in precise terms, the planned work load on the productive system in a very short run.

The area of scheduling is a very broad one and will often vary from organization to organization and sometimes from day to day. To classify the scheduling model, it is necessary to characterize the configuration of resources and the behavior of tasks. If the set of jobs available for scheduling does not change over time, the system is called static or deterministic. Whereas, if the jobs arrive over time, the system is called dynamic. Generally, the static models are more tractable than the dynamic models and are, therefore, subjected to more extensive study. Static models have often captured the essence of more complex, dynamic systems. Also, the analysis of the static problems have

frequently uncovered valuable insights and sound heuristic principles that are useful in more general cases.

Production scheduling is the final phase in production planning and typically covers much shorter time periods. This is the stage at which all the production activities are coordinated and projected on a time scale. A production schedule is, in fact, a timetable that tells what machine or department should be doing what and when.

Operation scheduling attempts to assign work to the required facilities in such a way that all costs associated with manufacturing are minimized. The costs are associated with factors such as utilization of machines, under or overtime of the work force, capital tied-up in the work-in-process, orders delivered late, and so on. The process of scheduling is, in a way, a concerned undertaking to minimize the aggregate sum of all these costs.

One of the important aspects of the planning and scheduling function is the dynamic nature of the decision process. The current decision is merely one of a sequence of decisions and, therefore, does not make a commitment for all time. An error in the forecast made for the past period on which decisions were based can be compensated for in the current period. Therefore, a decision is a commitment only until the time of the next decision.

2.0 SCHEDULING CRITERIA

Basically, three types of decision making goals seem to be prevalent in scheduling. They are efficient utilization of resources, rapid response to demands and close conformance to prescribed deadlines. Frequently, an important measure of system performance such as job lateness, job waiting time, machine idle time, or average work-in-process is used in the literature on scheduling.

There are numerous criteria that have been employed in theoretical studies of scheduling, and there are varying circumstances in which certain criteria take different relevance. The objective in any scheduling environment will generally be to minimize the cost that is chargeable to the scheduling decision. In most of the studies, a predominant criterion is used for sequencing the jobs. However, more involved work could consider multiple criteria or goals for such a decision.

There are over thirty different criteria, or measures of performance in scheduling which can be primarily classified as those that are regular measures of performance and those that are not. A regular measure of performance is one which has an objective function which can only increase if at least one of the completion time in the schedule increases. Furthermore, the measures of performance can also be grouped into primarily three major categories.

Table 6A.1 provides a list of the most commonly considered criteria in the literature on scheduling.

2.1 CRITERIA BASED ON COMPLETION TIMES

The performance measures of schedules are usually a function of the set of completion times in a schedule. This is a regular measure of performance and may be defined as a function of completion times $C_1, \ldots, C_n$ of jobs. The objective of a schedule may be to minimize the mean, weighted mean, or the maximum of completion times, or other regular measures in this category. The three most important measures are covered in the discussion below.

First, the maximum completion time is defined as the time, or interval, required to complete all the jobs. Minimizing the maximum completion time implies that the cost of a schedule depends on how long the processing system is devoted to the entire set of jobs. The total production time or the maximum completion time, is called the makespan time and is important to companies which make special products, for which short deliveries must be quoted. In these cases, scheduling for minimum makespan will enable shorter deliveries to be quoted and achieved.

Next, the total completion time and the mean completion time are important because of the investment tied up in the materials in stock and work-in-progress, in the factory. With assembled products, however, there is no particular

TABLE 6A.1 CRITERIA OF OPTIMALITY

I. CRITERIA BASED ON COMPLETION TIME

- Maximum Completion Time.
- Maximum Flow Time.
- Total Completion Time.
- Total Flow Time.
- Mean Completion Time.
- Mean Flow Time.
- Weighted Sum of Completion Time.
- Weighted Sum of Flow Time.
- Jobs Waiting Time.
- Weighted Job Waiting Time, etc.

II. CRITERIA BASED ON DUE DATES

- Maximum Lateness.
- Maximum Tardiness.
- Maximum Earliness.
- Total Lateness.
- Total Tardiness.
- Total Earliness.
- Mean Lateness.
- Mean Tardiness.
- Mean Earliness.
- Weighted Sum of Lateness.
- Weighted Sum of Tardiness.
- Weighted Sum of Earliness.
- Number of Tardy Jobs.
- Number of Early Jobs, etc.

III. CRITERIA BASED ON INVENTORY COST AND UTILIZATION

- Number of Jobs in the System.
- Machine Idle Time.
- Machine Weighted Idle Time.
- Man-power Idle Time.
- Man-power Weighted Idle Time.
- Utilization or Mean Utilization.
- Set-up Time, etc.

advantage in getting some parts through with makespan time, if they have to wait as work-in-process until the remaining parts arrive. Thus, a reduction in total or average completion time is sought. Minimizing the total completion time, or its average signify that the average time of the jobs and their raw materials should be at this minimum level and the cost of a schedule is directly related to the average time it takes to complete the jobs. Among the conditions which are likely to give minimum total completion time are those where there is plenty of available capacity and labor. The fact remains though that efficient scheduling can effect an improvement in total completion time and also incidentally in labor, plant, and capital utilization.

Finally, if the cost per time unit is different for each job, then the weight of each job is different. In such cases, the objective is to minimize the weighted sum of completion times. Here, the scheduling objective is to minimize the cost due to capital tied up in materials, therefore, the emphasis on each job is not the same. In other words, the measure of performance is modified to effect a realistic cost savings.

2.2 CRITERIA BASED ON DUE DATES

One of the important aims of scheduling is to plan the sequence of work, such that the production can be

systematically arranged with the intent of completing all products by the due dates. This means that all finished products must be ready for shipping to customers by their promised delivery date. Sets of made and bought parts must be ready for assembly by their due dates. Similarly, batches of castings must be ready for machining by their due dates.

Lateness, tardiness, and earliness are three different ways of comparing the actual completion time with the assigned due date. Lateness considers the algebraic difference for each job, regardless of the sign of the disparity. Tardiness considers only positive differences; jobs which are completed after their due date. There are some costs associated with late deliveries, like a decrease in good will, lost contracts, lost sales, bad public relations, and overall reliability, etc. Earliness considers only negative differences, that is, jobs which are completed ahead of their due dates. There are usually no positive rewards or negative costs for completing the jobs at an early date. Rather, sometimes these completed jobs have to sit in the warehouse awaiting dispatch to the customers, thereby incurring inventory carrying cost. The objective of a schedule may be to minimize the mean, weighted mean, or the maximum of lateness, tardiness, or earliness of jobs.

Sometimes it is not possible to delay a job beyond a certain time limit or the cost of delay past that limit is very high. An example is the completion of job beyond a

date when it is liable to be cancelled if it is not complete. In such cases, a reasonable objective would be to minimize the number of tardy jobs. This gives rise to other objectives in this category such as to minimize the number of tardy jobs, early jobs, or other measures in this group.

2.3 CRITERIA BASED ON INVENTORY COST AND UTILIZATION

It has already been noted that cost should be related to the production process as a whole and not just to its outcome as reflected by the completion time or the due date. A number of other possible alternate criteria such as the number of jobs in waiting and/or process, idle time or weighted idle time of manpower and/or machines, utilization of the machines, and others must also be considered.

The objective of minimizing the number of jobs in waiting is to reduce the work-in-process. Similarly, if the aim is to ensure the efficient use of the machines, then the objective may be to maximize the number of jobs in the process. Also, the objective could also be that of minimizing the average number of finished jobs because doing this will, in general, reduce the inventory cost of the finished goods.

The objective of minimum idle time on machines aims at maximum utilization of the plant. How far this objective is achievable depends in part on the balance of capacities in the factory. If, as usually happens, there is a limited

capacity on few a machines which are normally heavily loaded and there is excess capacity on the most of the remainder of the plant, attempts to achieve this objective should emphasize these heavily loaded machines. In other words, the weighted idle time needs to be minimized. Similar reasoning also goes for manpower idle or weighted idle time.

Such criteria, as discussed above, and others in this category are generally a composite function of two or more criteria discussed in the preceding subsections and mostly are not regular measures of performance.

3.0 SOLUTION METHODOLOGIES

There are numerous solution techniques that can be applied to the space shuttle scheduling problem. The choice can range from integer programming, mixed integer programming, linear programming, branch and bound algorithms, and simulation experimentations to heuristic procedures for single or multiple objectives. The optimal seeking techniques obviously have the advantage of arriving at an optimal solution, but the major drawback is in the computation time which makes them intractable for large problems.

The choice of the solution approaches to solve the stated problem depends upon the size and complexity of the problem, and the desired accuracy of results. The four more

frequently used approaches for sequencing problems are briefly discussed here.

3.1 GENERAL MATHEMATICAL PROGRAMMING

General mathematical programming includes linear, dynamic and integer programming as well as networks of flow, and others. In many cases, one or more of the above can be used to find the optimum solution in a conventional scheduling problem. In finding the solution for the FSMP problem, a mixed integer programming (MIP) formulation can be a very useful tool. But, in most instances this kind of formulation has served as a means of demonstrating its effectiveness only in some small size problems.

3.2 BRANCH AND BOUND ALGORITHM

The branch and bound approach consists of two fundamental procedures. The process consists of considering all potential solutions and eliminating from explicit consideration those particular solutions which are known from dominance, bounding, and feasibility considerations to be unacceptable. The algorithm maintains a list of all unsolved subproblems which have been encountered in the branching process, but have not been eliminated by dominance properties and whose own subproblems have not yet been generated. These are active subproblems, and it is

sufficient to solve all active subproblems to determine an optimum solution.

The drawback for branch and bound with elimination is the computation complexity for large problems. Even for relatively small problems, there is no guarantee that the solution can be obtained quickly. However, if optimality can be sacrificed for speed, different modifications such as using branch and bound without backtracking or with limited backtracking can be used to obtain speedy, near optimal, solutions.

3.3 SIMULATION APPROACH

The primary advantage of a simulation approach is that a solution for a large complex problem can be obtained in a reasonable length of time. Almost all types of scheduling problems can be attempted by the use of simulation since the procedures are generally simple to use. The simulation procedure can be performed in several ways. One way is to generate schedules at random, compare them and select the best schedule. Another way is to study the different priority or sequencing rules in order to gain understanding of the structure of the problem. The knowledge or understanding gained as a result of such a simulation study can then be used to recommend a simple priority rule for the sequencing of a given set of jobs at the work centers.

3.4 HEURISTICS

Most of the scheduling problems are NP-complete. The large scale FSMP scheduling problems may deliver the wrong impression that it is almost impossible to come up with an optimum or near optimum solution in a feasible amount of computation time. Nonetheless, in practice we cannot leave these problems unsolved. They have their basis in reality and the requirement is that of finding an efficient solution, using intelligent methodology, in a realistic time frame. Using the knowledge and experience gained from the structure of the problem, then it is necessary to find a sequencing rule for scheduling, which if not optimal, may at least be expected to perform better than average. Such methods which may not guarantee an optimum solution, but perform reasonably well under most circumstances are called heuristics.

APPENDIX VI B

BRANCH AND BOUND ALGORITHM FOR A FLOW SHOP WITH MULTIPLE PROCESSORS

1.0 INTRODUCTION

A flow shop sequencing problem is characterized as the processing of n jobs on m machines. The machines are laid out in a unidirectional flow pattern and each job is processed identically in the fixed ordering of the machines. The objective of job scheduling can be that of minimizing the maximum completion time required to complete the processing of all of the jobs on all of the machines (makespan), the average time to complete all of the jobs (mean flow time), or any other regular measure of performance. More detailed work could involve the optimization of multiple objectives, or goals.

The sequencing of a flow shop with multiple processors (FSMP) at each stage is a generalization of the flow shop problem. It involves sequencing of n jobs in a flow shop where, for at least one stage, the processor has more than one identical machine. Stated another way, the problem is a special case of a general job shop problem in which all jobs to be scheduled follow the same machine sequence and there is more than one machine for at least one stage. The problem was first identified by Salvador (1973). He

suggested a branch and bound approach to solve the problem for the permutation FSMP. Wittrock reports more work on the development of periodic (1985) and nonperiodic (1988) scheduling heuristic algorithm. He calls the problem as flexible flow lines and proposes to solve it by decomposing into primarily two subproblems; the first one consists of machine allocation, and the other is that of sequencing jobs on each machine. The two authors also points out numerous real life applications of the problem. Kochlar and Morris (1987) report work on the development of the heuristics which considers setup times, finite buffers, blocking and starvation, machine down time, and current and subsequent state of the line. The heuristics developed try to minimize the effect of setup times and blocking. Further work has been reported by Brah and Hunsucker (1987) in the development of mathematical formulation, primarily useful for small size problems. However, much work still remains to be done and there is a need for an in depth study to determine methods of solving widespread problems.

The purpose of this paper is to present a branch and bound algorithm to solve scheduling problem of minimizing the makespan in a FSMP. The lower bounds and elimination rules developed in this paper for the makespan criteria are based upon the generalization of the flow shop problem. They have substantially helped to exhibit the usefulness of the algorithm for much larger problem size. Furthermore, a computational algorithm, along with results, is presented to

demonstrate the working of the solution method. The branch and bound algorithm can also be used to optimize other measures of performance.

2.0 BACKGROUND

An important aspect when dealing with the scheduling problems is that even the simplistic case of a static flow shop minimizing the makespan belongs to the family of combinatorial problems. The complexity of the problem is further increased by the fact that unlike the single machine case, the inserted idle time may be advantageous. Further, it has also been shown that the three or more machine permutation flow shop and job shop problems are NP-complete problems (Gonzalez and Sahni 1978). Therefore the complexity of the problem strongly suggest that an exact polynomial bounded method for solution is highly unlikely. Further discussion on the complexity of the scheduling problems, among others, is contained in Garey et al. (1976), Garey and Johnson (1979), King (1979), and Cho and Sahni (1981).

3.0 PROBLEM DESCRIPTION

The problem of FSMP scheduling can be presented graphically as in Figure 6B.1. There is a main queue of incoming jobs, and each job can advance to any one of the M_1 machines at stage 1. As can be seen in Figure 6B.2, there

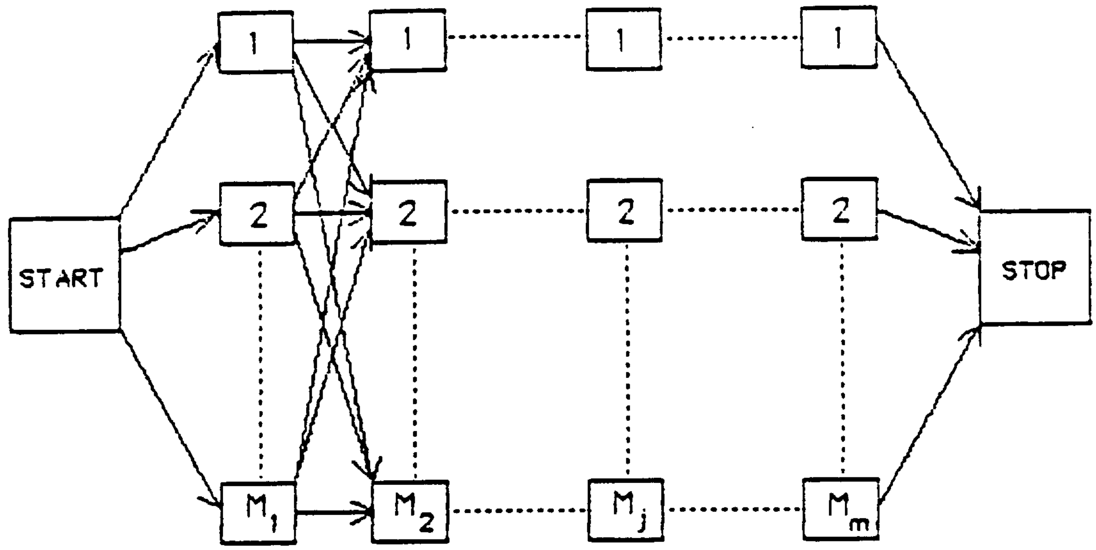

FIGURE 6B.1 SCHEMATIC REPRESENTATION OF A FLOW SHOP WITH MULTIPLE PROCESSORS.

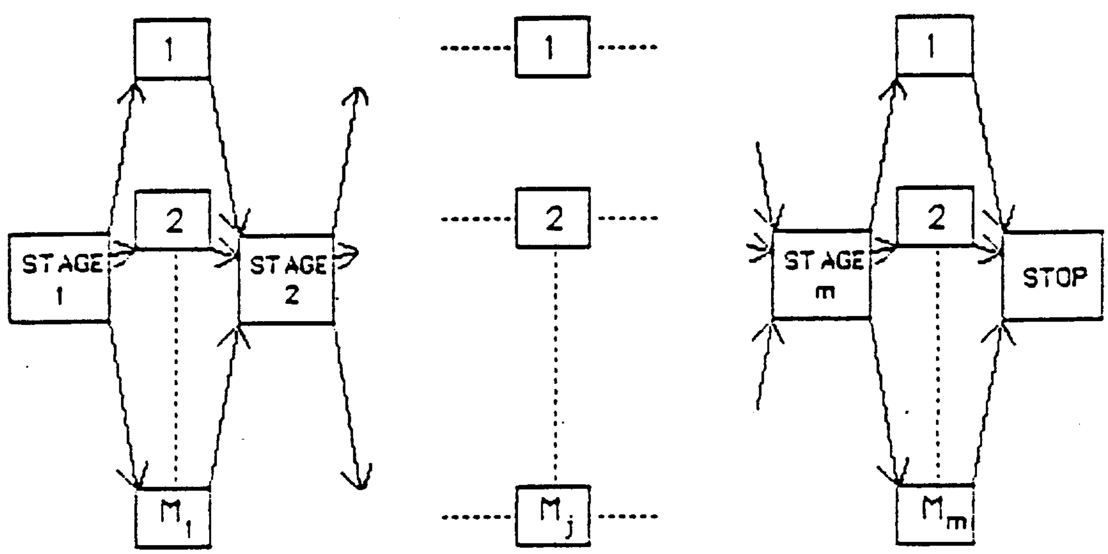

FIGURE 6B.2 QUEUING REPRESENTATION OF A FLOW SHOP WITH MULTIPLE PROCESSORS.

is a queue at each stage of the flow shop processing, and theoretically all of the jobs can be routed to any one of the M_j machines ($1 \leq j \leq m$) at stage j. When the job has been processed through the last stage m, using one of the M_m machines, it is complete and at that point can leave the system. As is shown by Brah and Hunsucker (1987), the jobs can take $\prod_{j=1}^{m} \binom{n-1}{M_j-1} \frac{n!}{M_j!}$ possible sequence combinations, or paths for a schedule.

Before an effort is undertaken to understand the sequencing process, it will be wise to limit the study to reasonable bounds by making some assumptions. In order to achieve the limiting of the varieties of arrangements, the following assumptions are therefore made:

- Each job is an entity, even though the job is composed of distinct operations, no two operations of the same job may be processed simultaneously.
- The number of jobs is known and fixed. No job may be cancelled before completion.
- The arrival time, or release time, of the jobs is known and fixed.
- The processing times of the jobs are known and constant.
- Setup time is considered a part of processing time.
- Setup time is independent of the job sequence.
- All jobs follow the same machine sequence.

- No job may be split or pre-empted.
- The flow shop consists of $m \geq 2$ stages or levels.
- Each level or stage has $M_j \geq 1$ machines; $j = 1, \ldots, m$; with inequality holding for at least one M_j.
- All machines are available at the beginning and never breakdown during the scheduling period.
- No machine may process more than one job at a time.
- Machines may remain idle.
- In-process inventory is allowed.

4.0 APPLICATIONS OF THE PROBLEM

The application of this type of problem occurs more often than one would imagine. Many high volume production facilities have several independent flow shops. The process in such facilities is such that machines are interchangeable at each stage and are therefore practically similar. Salvador (1973) first recognized the problem in the polymer, chemical, process and petrochemical industries where there are several parallel plants which can be considered as flow shops, and the jobs can practically be processed at any one of the plants at each stage of the processing. Assembly lines, in which more than one product is manufactured and each work station has multiple machines, is also an obvious application of this problem. Similarly, the situation where a parallel machine(s) is (are) added at one or more stages of the flow shop to ease the pressure on bottle neck

facilities, and/or to increase the production capacities can be viewed as an application of the suggested problem.

Similarly, there are situations analogous to production systems where the similarity of a FSMP can be established. Consider for example the running of a program on a computer for a language like FORTRAN. The three steps of compiling, linking and running are performed in a fixed sequence. If there are multiple jobs (computer programs) requiring all of these facilities (steps), each having multiple processors (softwares), the process resembles that of a FSMP. There are similar examples in computers, telecommunications, group technology applications, flexible manufacturing systems, and others. The objective function in all of these functions could be the optimization of any one or more regular measures of performance.

5.0 BRANCH AND BOUND PROCEDURE

The absence of algorithms to solve most real life scheduling problems has given rise to the effort to use general purpose optimization methodologies such as mathematical and dynamic programming, and branch and bound techniques. These methods, however, require quite extensive computations in order to find an optimum solution for large scale problems. Other efforts have been concentrated on developing near optimal solutions by way of useful heuristics. In most studies involving heuristics, the

optimal solution though branch and bound techniques have been most widely used to examine their performance.

Basically, the branch and bound methods are related to dynamic programming in the sense that both are enumeration techniques that are expected to perform partial enumeration in most of the cases. Both branch and bound and dynamic programming are optimizing techniques which apply to a much larger class of problems than just those in production scheduling. They explore the decision tree in an intelligent fashion and in essence, use an implicit enumeration method to determine on route which branches need to be fully explored. Further, the efficiency of the branch and bound algorithm depends upon the selection of lower and upper bounds and elimination rules, which in turn establishes the breadth of the search tree.

The branch and bound methods in flow shop scheduling have been widely used for finding optimal or near optimal solution methods. Ignall and Schrage (1965), Lomnicki (1965), McMahon and Burton (1967), Ashour (1970), Gupta (1970), Lageweg et al. (1978), and Bansal (1979) among others have developed different branch and bound methods for various measures of performance like makespan, mean flow time, mean tardiness and maximum tardiness. The difference and the efficiencies of the branch and bound algorithms is in the choice of the lower bound and elimination rules. The strong bounds and elimination rules eliminate relatively

more nodes of the search tree which very often brings in more computation requirements as well. If such needs are excessively large, it may become advantageous to search through larger nodes using a weaker, but fast computable lower bound. However, the advantages of stronger bounds and elimination rules are more substantial in large scale problems (Baker 1975).

The branch and bound algorithm of a FSMP consist of three basic steps; the calculation of lower bounds, branching, and node elimination. The branching procedure can take place through several selection rules like the least lower bound, first come first served, or depth first least lower bound rule, etc. (Kohler and Steiglitz 1976). The nodes exploring process can take advantage for computational techniques like parallel processing. It can also use different search procedures such as a filtered beam search technique (Ow and Morton 1988). In any situation, as soon as the lower bound of the node equals or exceeds the upper bound of the complete problem, the node is eliminated from further consideration. Naturally, a characteristic function like makespan, mean completion time, or any other measure of performance can be used to eliminate a partial permutation which does not have a feasible and/or optimal solution.

To begin with, some notation is needed. Let:

n = Number of jobs;

m = Number of stages;

i = The job number, $i = 1, \dots, n$;

j = The machine stage number, $j = 1, \dots, m$;

M_j = The number of parallel machines at stage j;

p_{ij} = Processing time of job i at stage j;

N = A set containing all jobs;

A = A set of some jobs such that $A \subset N$;

A' = A set of jobs containing all jobs in the set A, and a job q, where $q \notin A$.

6.0 DETERMINATION OF LOWER BOUNDS

In order to solve the problem of optimal, or near optimal, scheduling in a FSMP using the branch and bound method, a related sub-problem must be solved. This problem involves finding a lower bound on each node for the desired performance measure. To find such a lower bound at each branching node, two contiguous partial schedules must be considered. Let the first of these partial schedules (i.e. the partial sequence at the start of the schedule) involving all jobs on all machines through stage j-1, along with the sequence of job set A, at stage j, be represented by $S_j(A)$. Also let A' represent the augmentation of an unscheduled job q at stage j to the set of jobs A, such that $q \notin A$. Then, $S_j(A')$ represents a schedule formed by appending job q to $S_j(A)$. The second schedule, $S_j'(N-A')$, will consist of the remaining jobs not contained in the schedule $S_j(A')$ at

stage j, and all jobs beyond stage j in an arbitrary sequence. The notation $S_j(A')S_j'(N-A')$ will then be used to represent a complete schedule of jobs at stage j and all subsequent stages.

For a given partial sequence $S_j(A)$, let $C[S_j(A), k]$, represent the completion time of the partial sequence on machine k belonging to one of the M_j parallel machines at stage j. The equations involving completion times of the partial sequence $S_j(A')$ on each machine k can be calculated recursively as follows:

$$C[S_j(A'), k] = \begin{cases} \max\{ C[S_j(A), k]_{q\varepsilon k}, C[S_{j-1}(A'), k_1]_{q\varepsilon k_1}\} + p_{qj} & \text{If } q \text{ is processed on } k, \text{ at stage } j. \\ C[S_j(A), k] & \text{Otherwise.} \end{cases} \quad (6B.1)$$

where

$$C[S_0(A), 0] = C[S_j(\phi), k] = 0 \quad \text{for all } j \text{ and } A.$$

and

$C[S_0(A), 0]$ = Completion or arrival time of all jobs at the start of processing;

$C[S_j(\phi), k]$ = Completion time of the empty set at stage j.

Thus in order to minimize the maximum completion time, $\max_k \{C[S_m(N), k]\}$, must be minimized. Here, $S_m(N)$ is the

complete sequence of all jobs at the last stage. Similarly in order to minimize the mean completion time of the jobs, $\sum_{i=1}^{n} C[S_m(i), k] / n$, needs to be minimized.

Several researchers have developed branch and bound formulations of the flow shop problem. The major difference in the approaches has been in the calculation of the lower bounds. A variety of lower bounds for minimizing the makespan have been developed which can generally be classified as machine based bounds, job based bounds, and composite bounds. These lower bounds for the flow shop are discussed by Gupta (1970) and Baker (1975). Their results are used in this research as a basis for the development of lower bounds which is presented below for a FSMP. Salvador (1973) has also developed machine based bounds for the permutation FSMP. The machine based bounds developed here, however, are generalized lower bounds for the FSMP problem which considers permutation and other schedules. Moreover, it turns out that the computation requirements of the machine based bounds developed here are much less, since only a subset of jobs are explored. Besides, it also results in making them stronger lower bounds, therefore considerably decreasing the number of nodes searched. Furthermore, job based lower bound and elimination rules proposed here also serves to reduce the number of nodes explored in the branching tree.

6.1 MACHINE BASED BOUNDS

If a job q is being considered for augmentation to a partial schedule $S_j(A)$ at stage j, then for a FSMP scheduling problem, the unprocessed work load at any stage can be utilized in obtaining a lower bound for minimizing the makespan on that stage. Let the average completion time and processing requirement for stage j be represented as,

$$ACT[S_j(A')] = \{ \sum_{k=1}^{M_j} C[S_j(A'), k] \} / M_j + \{ \sum_{i \varepsilon (N-A')} p_{ij} \} / M_j.$$

The terms on the right hand side of the above equation are:

- o The average interval over which the machines are already committed after scheduling job q at stage j;
- o And the remaining average work load of unprocessed jobs required of machines M_j, at stage j.

First we will show that $ACT[S_j(A')]$ is a lower bound on the completion time of the jobs through stage j if this was the last stage of processing. Then we will develop the complete lower bound for the branching node. As defined above, $ACT[S_j(A')]$ is the average completion time of the jobs formed from the set of scheduled jobs A' and the remaining set of jobs N-A' in an arbitrary sequence on stage j. By definition $ACT[S_j(A')] \leq \max_k \{ C[S_j(N), k] \}$,

where $S_j(N)$ is the composite schedule of all jobs. Moreover, the jobs in N-A' must be assigned to some processors at stage j, which means that,

$$ACT[S_j(N)] = \{ \sum_{k=1}^{M_j} C[S_j(N), k] \} / M_j.$$

Since the average is less than the maximum, $ACT[S_j(A')]$ is the lower bound on the completion time up to the stage j.

Further, let the maximum completion time for a scheduled workload be represented as,

$$MCT[S_j(A')] = \max_k \{ C[S_j(A'), k] \}.$$

Note that $MCT[S_j(A')]$ is also a lower bound if stage j was the last stage of processing. Now, if it were possible to determine which job finished last on the stage j, then adding the remaining work load of the job will provide a lower bound on the makespan. However, the best that may be possible is to determine the conditions which predicate the set from which the last job comes. In order to compute the lower bound of the branching node at stage j, consider the following situation. If $ACT[S_j(A')]$ is greater than or equal to $MCT[S_j(A')]$, then obviously, in all cases, one of the remaining unscheduled jobs will be the last job processed at stage j, i.e., the last job at stage j comes from the set of jobs N-A'. Otherwise, if $ACT[S_j(A')]$ is less than $MCT[S_j(A')]$, then the last job may come from

either the set of jobs in A' or N-A'. Nevertheless, the jobs in N-A' will dominate all other jobs.

Once we know the set of jobs from which the last job comes, the job in that set with least work remaining could provide the best possible results for minimizing the makespan. This gives the machine based lower bound for the branching node for stage j as follows,

$$LBM[S_j(A')] = \begin{cases} ACT[S_j(A')] + \min\limits_{i \in N-A'} \sum\limits_{j'=j+1}^{m} p_{ij'} & \text{If } ACT[S_j(A')] \geq MCT[S_j(A')] \\ MCT[S_j(A')] + \min\limits_{i \in A'} \sum\limits_{j'=j+1}^{m} p_{ij'} & \text{Otherwise.} \end{cases} \qquad (6B.2)$$

6.2 JOB BASED BOUNDS

The calculations for a job based bound focuses on the remaining processing required of each unscheduled job at each stage j. In a flow shop, there is only one route available for the jobs to process, which is not the case in a FSMP. Meaning, a job based bound for a FSMP cannot be as strong due to the presence of alternate routes for the other jobs in the set. Gupta (1970), and Baker (1975) give the following lower bound for the flow shop problem where only a single processor is permitted at each stage of processing,

$$LBJ[S_j(A')] = C[S_j(A), k] + \max_{i \varepsilon N-A} \sum_{j'=j}^{m} p_{ij'} + \sum_{r \varepsilon N-A'} \min [p_{rj}, p_{rm}].$$

The last term of the above equation holds only if there is only one processor at each stage. A modification of the above job based bound can be constructed by considering the unscheduled jobs in the set N-A' at stage j. All of the jobs in this set have to be scheduled and completed both on stage j and the rest of the processing stages. Therefore, if the maximum of these times is added to the shortest completion time of $S_j(A')$, the job based bound is determined. This gives the lower bound for the problem as,

$$LBJ[S_j(A')] = \min_{k} \{C[S_j(A'), k]\} + \max_{i \varepsilon N-A'} \sum_{j'=j}^{m} p_{ij'}. \tag{6B.3}$$

The advantages of the job based bound will become apparent when the number of jobs is close to the number of parallel processors at each stage. A reasonable assumption is that the dominance of the job in establishing a lower bound is more profound when there are less jobs for each parallel machine. Based upon a similar rationale, the usefulness of the job based bound in a FSMP is expected to be effective towards the end of the schedule at each stage. Also, the conditions which makes the bounds weaker are unexpected forced idle time on the machines and waiting times on the job. The job based bounds are generally more

sensitive to such conditions and their effect is greater when the number of jobs and/or stages is large in a FSMP. Baker (1975) reports that job based bounds do not appear to be very effective for a flow shop problem. He suggests that they can be effective, if used in conjunction with the machine based bounds. This conjecture also seems to apply to a FSMP.

6.3 COMPOSITE BOUNDS

If we combine the job based bound with the machine based bound for computing the lower bound for a FSMP, we obtain a composite lower bound. McMahon and Burton (1967) have also suggested a similar composite lower bound based on the jobs and the machines for a pure flow shop. Therefore, the composite bound for a FSMP for the branching node at stage j ($1 \leq j \leq m$) is as follows,

$$LBC[S_j(A')] = \max\{LBM[S_j(A')], LBJ[S_j(A')]\}. \quad (6B.4)$$

7.0 ELIMINATION METHODS

Elimination methods for the flow shop scheduling problem have been investigated by several authors. Szwarc (1971) presents a review of the successes and failures of elimination procedures and derives some properties. Baker (1975) discusses these methods and presents results which suggests that elimination strategies are not very useful by

themselves. However, when elimination procedures are used in conjunction with lower bounds, they have been shown to be quite effective especially for large size problems. Nevertheless, the elimination strategies developed by Szwarc (1971, 1978), and further evaluated by Baker (1975) are primarily designed for permutation flow shop. They have their best utilization in the special case of a permutation FSMP, where the number of parallel processors at each stage is the same, meaning the machine allocation and sequencing decision is only made at the first stage.

Furthermore, the dominance conditions developed by Gupta (1975), Szwarc (1977), and Gupta et al. (1987) for the flow shop problem are applicable to the FSMP problem provided the jobs being compared use the same processors at all stages of processing. This is to say, that the set of jobs which are assigned to a particular processor at stage one will be assigned together to some processor at each subsequent stage, so jobs in some sense are grouped together. In this situation, there exists a flow shop inside the general problem of a FSMP for that subset of jobs. The best known dominance conditions as proposed by the above authors are briefly discussed here. Their use in the general case is rather limited. Nonetheless, the insight provided by them can be helpful for a FSMP.

7.1 KNOWN DOMINANCE CONDITIONS FOR THE FLOW SHOP PROBLEM

In order to explain the dominance conditions, let us consider $S_j(A)$ and $S^*_j(A)$ as permutations of the same jobs through the same set of processors at all stages of processing upto stage j. In general, the sequence $S_j(A)$ is said to dominate $S^*_j(A)$ (see Gupta 1971, Szwarc 1973) if,

$$C[S_j(A)] \leq C[S^*_j(A)] \qquad \text{for each } 1 \leq j \leq m.$$

Further, consider $S_j(A")$ which is different than $S_j(A')$ in that it contains a job r which precedes job q, and such that neither r nor q is in A. According to Szwarc (1978), the best known job dominance condition for any partial sequence $S_j(A")$ over $S_j(A')$ is said to hold if,

$$C[S_j(A")] - C[S_j(A')] \leq p_{rk} \quad \text{for all } (1 \leq j \leq k \leq m).$$

Further improvements on the job dominance conditions of the flow shop in terms of being less restrictive are presented by Gupta et al. (1987).

7.2 SOME EXTENSIONS FOR FLOW SHOP WITH MULTIPLE PROCESSORS

The following are some of the other obvious guidelines which can be used for the FSMP problem:

Recall that A' is the augmentation of job q to A. Now, consider A" as the augmentation of job r to A on the same

processor as job q on stage j. Then the node $S_j(A'')$ may be eliminated from further consideration if,

$$C[S_j(A'), \underset{q \varepsilon k_j}{k_j}] \leq C[S_{j-1}(A''), \underset{r \varepsilon k_{j-1}}{k_{j-1}}];$$

Here, $q \varepsilon k_j$ means that q was processed on processor k_j at stage j. The above relationship implies that if job q can finish processing at stage j before job r becomes available for processing at the same stage, then it is sufficient to consider a sequence on a processor k_j in which job r follows job q.

Also, if the augmentation of any job to A at stage j yields a lower bound which equals or exceeds the upper bound of the complete problem, then the node emanating from augmentation need not be considered. The upper bound of the problem is the best value of the complete schedule computed so far. As an initialization step, the upper bound of the problem would be set equal to a large number (larger than any possible schedule value) at the start.

Further, some other guidelines are presented in the form of the following two theorems. The first theorem is an extension of the flow shop results and is applicable in special situations as explained in its definition. The second one is a generalized theorem showing that for the maximum completion time criteria, it is sufficient to consider the nondelay schedules for the jobs going to a common processor at the last stage of processing in a FSMP.

__THEOREM 6B.1__: Suppose there exists two jobs r and q such that r directly preceeds q on a common processors k_1 at stage 1 of a FSMP. Further assume that jobs r and q also use a common processor k_2 at stage 2. Then among the set of schedules with this property, for any regular measure of performance, it is sufficient to consider schedules in which the same processing sequence for r and q is followed on k_1 and k_2.

__PROOF__: Consider a schedule which has job r directly preceding job q on a processor k_1 at stage 1, and r following q, with perhaps some intervening jobs, on a processor k_2 at stage 2. On stage 1, we can exchange the order of processing of q and r without increasing the starting time of any other jobs on k_2. Therefore, this exchange cannot increase the completion time or any regular measure of performance of such jobs.

As a direct consequence of Theorem 6B.1, the following corollary holds.

__COROLLARY 6B.1__: Suppose there exists a set of jobs J which uses a common processor k_1 at stage 1 and k_2 at stage 2 of a FSMP. Then among the set of schedules with this property, for any regular measure of performance, it is sufficient to consider schedules in which the same processing sequence for the jobs in J is followed on k_1 and k_2.

THEOREM 6B.2: Suppose there exists jobs r and q in a FSMP that use a common processors k_m at stage m. Then among the set of schedules with this property, for the maximum completion time criteria, it is sufficient to consider schedules in which the processing sequence for r and q on k_m is the same as the arrival sequence from stage m-1.

PROOF: Consider a schedule which has job r finishing before job q on stage m-1, and has r following q, with perhaps some intervening jobs, on the same processor at stage m. Suppose we move job r immediately ahead of job q on k_m. Job r can then start no later than the previous starting time of job q on k_m since it finished before q on stage m-1. The most that can happen to job q and the jobs that may have been between r and q is that their completion times get increased by p_{rm}. Nevertheless, the processing time on the processor k_m can only be expedited, therefore, the maximum completion time cannot increase by the adjustment.

As a direct consequence of Theorem 6B.2, the following corollary holds.

COROLLARY 6B.2: Suppose there exists a set of jobs J which uses common processors k_{m-1} at stage m-1 and k_m at stage m of a FSMP. Then among the set of schedules with this property, for the maximum completion time criteria, it is sufficient to consider schedules in which the same

processing sequence for jobs in set J is followed on k_{m-1} and k_m.

8.0 THE ENUMERATION OF ALL SEQUENCES

There are two decision activities which occur at each stage of the scheduling problem. The first decision is the assignment of the jobs to a specific machine k from M_j parallel machines, at stage j, and the second is the scheduling of jobs on every machine at that stage. The two decisions are closely linked and both of them effect the quality of the scheduling result. The enumeration method of Bratley et al. (1975) for scheduling on parallel machines has been used with some modification for the FSMP problem.

The enumeration of the problem is accomplished by generating a tree which contains two types of nodes. If the path passes through node i, then the candidate job i is scheduled on the current machine. While, if the path passes through node $\boxed{i}$, then this job i is scheduled on a new machine, which now becomes the current machine. The number of $\square$ nodes on each branch establishes the number of parallel machines used by that branch, and obviously that must be less than or equal to the number of parallel processors M_j, at stage j. However, if the processing time and the cost of processing for all parallel machines $k \varepsilon M_j$ at stage j is the same, and the number of jobs is greater than or equal to the number of parallel processors M_j, for all j, then for any

regular measure of performance it is not advantageous to keep one of the parallel machine idle for the entire duration, while the others are processing the jobs. Using this, the number of possible branches at each stage j, as established by Brah and Hunsucker (1987), would be,

$$N(n,M_j) = \binom{n-1}{M_j-1} \frac{n!}{M_j!}. \tag{6B.5}$$

This means, for an optimization problem of a flow shop with M_j processors at each stage j, the total number of possible end nodes equals,

$$S(n,m,M_j) = \prod_{j=1}^{m} \binom{n-1}{M_j-1} \frac{n!}{M_j!}. \tag{6B.6}$$

In order to construct a tree that has been discussed above for the stated problem, some definitions and rules at each stage j are necessary. Let the level O_j represent the root node at stage j, and 1_j, 2_j, ... , n_j represent different levels of the stage, with n_j being the last, or the terminal level of stage j. Since there are n jobs and m stages, the total number of levels will be n*m. The last level of the whole tree will be n_m corresponding to the terminal level of the last stage. The following are the necessary rules for the algorithm to develop the branching tree of the problem under consideration.

<u>RULE 1</u>: Level O_j contains only the dummy root node of stage j of the problem ($1 \leq j \leq m$).

RULE 2: Level 1_j contain the nodes $\boxed{1}$, $\boxed{2}$, .. , $\boxed{x}$, where $x = n - M_j + 1$.

RULE 3: A path from level 0_j to level i_j, $[(1 \leq i < n) \& (1 \leq j \leq m)]$ may be extended to the level $(i+1)_j$ by any of the nodes $\boxed{1}$, $\boxed{2}$, ..., $\boxed{n}$, ①, ②, ..., ⓝ provided the Rules 4 to 7 are observed.

RULE 4: If $\boxed{k}$ or ⓚ has previously appeared as a node at level i_j, then k may not used to extend the path at that level.

RULE 5: $\boxed{k}$ may not be used to extend a path, at level i_j, which already contains some node $\boxed{r}$ with $r > k$.

RULE 6: No path may be extended in such a manner that it contains more than M_j square nodes at each stage j.

RULE 7: No path may terminate in such a manner that it contains less than M_j square nodes at each stage j unless the number of jobs is less than M_j.

Rule (1) is simply an indicator of the starting of a new stage. Rule (2) says that the first level of a stage j can only have x square nodes, where x is the index of jobs whose value is equal to $(n - M_j + 1)$. Any number larger than x will violate some of the other rules, specifically

Rules (5) and (7), and thus cannot be used to generate a square node at the first level. Rule (3) simply states that all unscheduled jobs at stage j are candidates for square and circle nodes as long as they do not violate any other rules, namely Rules (4) to (7). Rule (4) is necessary to assure that no job is sequenced twice at one stage. Rule (5) is to avoid duplicate generation of sequences in the branching tree. The number of square nodes in the branching tree establishes the number of processors used in the sequence, and Rule (5) guarantees that no more than M_j processors are used at stage j. Finally, as discussed before, there is no advantage in keeping a processor idle when the cost of processing is the same for all of the processors, thus Rule (7).

Figure 6B.3 gives a sample tree representation of a four job two parallel machine scheduling problem. The branching tree has thirty six end nodes. In seeking an optimal schedule, all of these end nodes can serve as a starting point for the next stage, which is O_{j+1} ($j < m$). Now, all of the nodes at subsequent stages may not be candidates due to their higher value of lower bounds. Therefore, not all of the nodes need to be explored. Incidentally, it may be observed that all of the jobs at stage j will not be readily available at the next stage and consequently inserted idle time will increase their lower bound and thus possibly remove them from further consideration. In other words, the sequencing pattern from

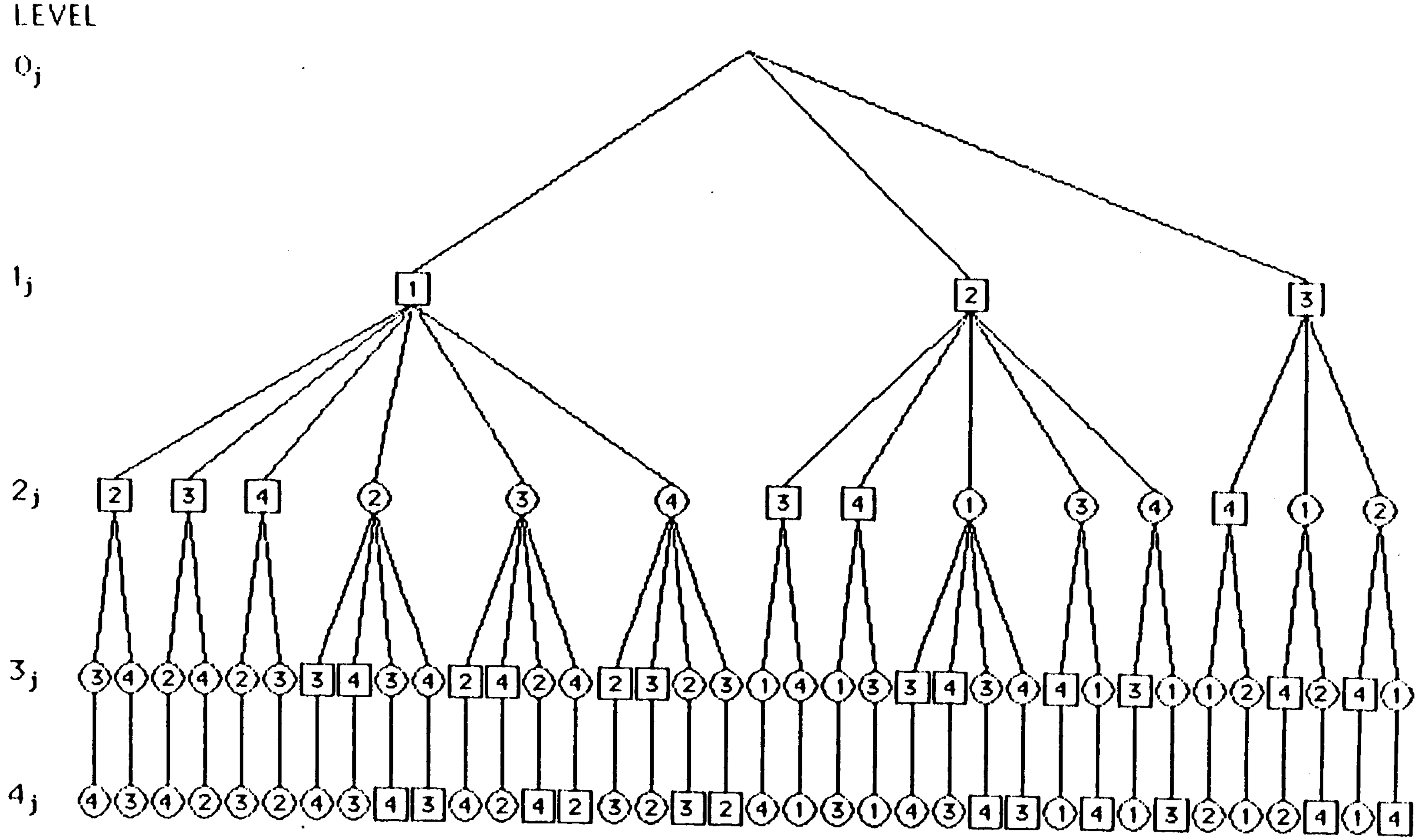

FIGURE 6B.3 TREE REPRESENTATION OF FOUR JOBS ON TWO PARALLEL PROCESSORS.

stage to stage is not expected to deviate considerably in most real life situations, unless the data is so structured. This situation will help to reduce the span of the search tree. Moreover, the requirement of processing times on individual jobs and the difference in the number of parallel processors at each stage, etc., will further establish the breadth of the search tree.

In addition to the above, if the interest is in the subclass of the active schedules called nondelay schedules, then the number of search nodes could be further reduced. Nondelay schedules are defined as those in which no machine is kept idle when it could start processing some operation. The use of nondelay schedules does not necessarily provide an optimum solution. Nonetheless, the decrease in the number of the nodes searched provides a strong empirical reason to generate such schedules (French, 1982). Such procedures could be useful for large size problems, where the speed of computation becomes critical.

9.0 DEVELOPMENT OF A COMPUTATIONAL ALGORITHM

The selection of a search method for the branch and bound algorithm is a function of several factors of which the most significant ones are the available memory size of the computation machine and the problem dimensions. Based upon these considerations, the branch and bound algorithm for a FSMP developed here uses a variation of the depth

first least lower bound search technique. Knowing the constraint on the memory size, this allows a fairly large problem size to be solved using this method. Furthermore, the computation speed of the algorithm has been observed to be consistently fast even for problems of modest size, although no comparisons are available to justify the claim. The branch and bound algorithm for generating a solution for optimizing makespan is as follows:

STEP 1: Generate 1, ..., $(n-M_1+1)$ square nodes at stage 1, and compute their lower bounds. Encode the necessary information about the nodes, and add them to the list of unprocessed nodes. Also, initialize a node for the termination of the computational algorithm.

STEP 2: Remove a node from the list of unprocessed nodes with the priority given to the deepest one in the branching tree with the least lower bound. Break ties arbitrarily.

STEP 3: Procure all information about the retrieved node. If this is one of the end nodes of the branching tree go to Step 5, while if this is the last node of the unprocessed nodes list then go to Step 6, otherwise move to the next step.

STEP 4: Generate branches from the retrieved node using the algorithm for node generation and compute

their respective lower bounds. Discard the nodes with the lower bound value larger than the complete solution. Add the remaining nodes to the list of unprocessed nodes and go to Step 2.

STEP 5: Save the current complete branching path, or schedule, as the best solution of the problem. If this is the last branch of the branching tree, or if the limit on the number of iterations and/or computation time has reached, then proceed to the next step, otherwise go to Step 2.

STEP 6: Print the results and stop.

The flow diagram of the branch and bound algorithm for a FSMP is presented in Figure 6B.4. The algorithm, coded in FORTRAN, consists of three major parts; the branching tree generation, the lower bound computing, and the list processing part. The branching tree generation and the lower bound computation part use the algorithms developed earlier in this paper. Basically, the job and machine based bounds, with a slight modification to the procedures of computing the lower bound, are used for the computation of lower bounds. This modification in computing the lower bound arises due to the structure of the branching tree generation algorithm. In the branching tree generation algorithm, a square node on the branching tree indicates the end of use for the last processor and the start of processing of jobs on a new processor. So if this branch is

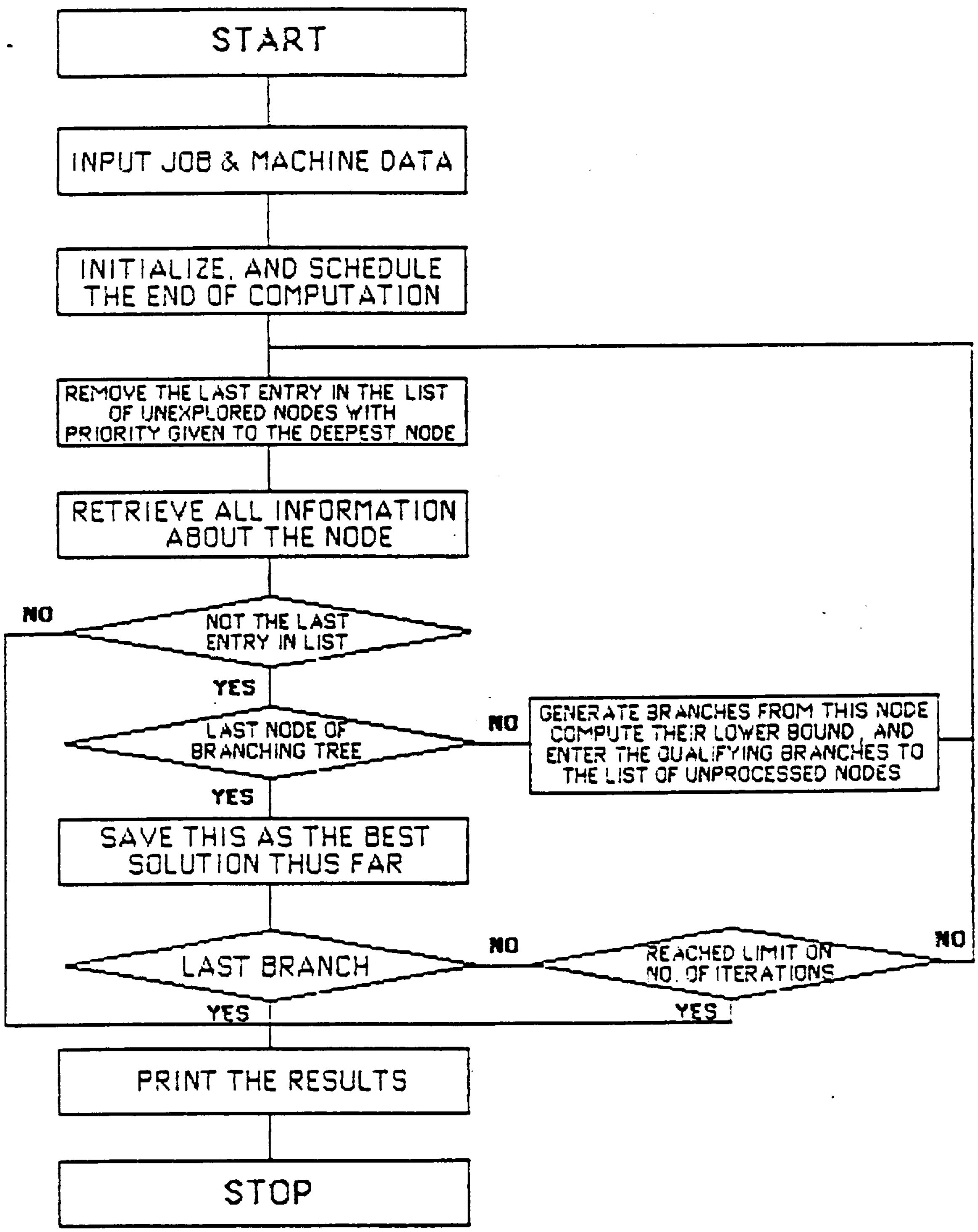

FIGURE 6B.4 FLOW DIAGRAM FOR THE SOLUTION METHOD OF THE BRANCH AND BOUND ALGORITHM.

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to be followed, the remaining unscheduled jobs at this stage must be scheduled only on the leftover processors. This information makes the lower bound more effective since the processing time at stage j of the unscheduled jobs need only be divided by the number of remaining processors. Further, because of the depth first least lower bound search method used in the development of the computational algorithm, it is simple to keep track of all the jobs until that point of the branching tree. The added information makes it possible to search through a relatively small set of jobs for establishing the lower bound of the branching node. The third part of the algorithm is list processing of the nodes. For the list processing part, the information is first coded for each branching node. If the lower bound on this branch is better than the best available lower bound of a complete solution, provided it is available at the moment, the branching node is stored in the list of unprocessed nodes. The following is the information stored for each one of the branching nodes:

KODE = NPR x 1000000 + NPS x 10000 + LSN x 100 + JOB.

LBND = NS x 10000000 + NSCH x 100000 + LB.

where

JOB = The index of job.

NS = The index of stage.

NSCH = The number in processing sequence.

LB = Lower bound of the branching node.

NPR = The processor number in use.

NPS = Sequence Number on this processor.

LSN = Last square node, or the index of the first job on the processor used by this job.

The stage and the level numbers, are coded in the diametrically opposite manner to their position in the tree. This is arranged so that the deepest node in the search tree has the least value. The list processing part, with this coding method, stores the deepest node on top and therefore makes it available to be retrieved first. In case two or more nodes are at the same stage and level, the one with the least lower bound is retrieved first and processed. Once the node is retrieved, the information on the node is decoded and compared against the last processed node data. Now, if the node has gone down a step in the branching tree, the necessary information, like sequence position and completion time of the job on the retrieved node, is established and recorded. On the other hand, if the retrieved node is at a higher or the same level as of the previous node, the working sequence and completion time matrix of the nodes lower than the present level and upto the level of the last node are re-initialized. The lower bound is then compared against the best known lower bound, provided it is available, and is either eliminated or branched except when this is the last node of the branching tree. Now, if this is not one of the last node of the branching tree, then branches are generated using the tree

generation algorithm. The qualifying nodes are stored in the list of unprocessed nodes following the deepest node with the least lower bound first rule. However, in case it is the last node of the branching tree, and if it satisfies the lower bound comparison test, the working sequence position and job completion time matrix along with the completion time of the schedule is saved as the best known solution.

9.1 TESTING OF THE ALGORITHM

A question most frequently asked in an optimization study, like the one performed over here, is concerning the validation of the algorithm. The authentication process of the branch and bound algorithm for a FSMP developed here consists of two parts. The first part consists of the proof that the branching algorithm generates all possible paths and that the bounding procedure does not eliminate an optimal end node of the branching tree. The proof of this component has been successfully demonstrated in earlier sections of this paper. The second part of the validation process consists of the correctness of the computer program developed to solve the problem through the use of a algorithm. It is indeed no secret that the proof of correctness of a computer program of any complicated algorithm, like the one developed here, is fairly difficult. However, in order to satisfy this requirement, the branching

and bounding subroutines of the computer program were extensively tested for completeness and correctness. Furthermore, the results of the branch and bound algorithm for a FSMP were compared against a simple nondelay schedule generator of n! possible schedules. The optimal solution of the branch and bound algorithm tested successfully against the best solution of the n! nondelay schedules. Out of the fifty tests performed for comparative study, the branch and bound algorithm for a FSMP outperformed in twenty percent of the cases for the optimal makespan, and in all cases for the computation time.

9.2 AN EXAMPLE

TABLE 6B.1 PROCESSING TIME DATA FOR THE EXAMPLE PROBLEM.

JOBS

STAGES j \ i	1	2	3	4
1	10	25	10	20
2	20	20	30	10

Consider a two stage flow shop (m = 2) with two parallel processors at each stage of processing ($M_1 = M_2 = 2$). Further, let the processing time of each job i, at stage j

of processing be given as in the processing time matrix of Table 6B.1. The release time, and the travel time between stages is assumed to be zero. The problem at hand is that of scheduling four jobs (n = 4) in such a shop so as to minimize the maximum completion time.

The number of possible nodes at each stage j of a FSMP can be computed from equation (6B.5) as follows,

$$N(n,j) = \binom{n-1}{M_j-1} \frac{n!}{M_j!} = \frac{(3!)(4!)}{(1!)(2!)(2!)} = 36.$$

Which gives the total number of possible nodes from equation (6B.6) as,

$$S(n,m,M_j) = \prod_{j=1}^{m} \binom{n-1}{M_j-1} \frac{n!}{M_j!} = 36^2 = 1,296.$$

Now, if the interest was to generate a nondelay schedule, the problem has a feasible schedule (not generated by the algorithm), as presented in Figure 6B.5, with a makespan of sixty time units. However, the optimal schedule, as presented in Figure 6B.6, has a maximum completion time of fifty five time units.

9.3 RESULTS OF THE ALGORITHM

The branch and bound algorithm developed in this research, generates optimal schedules for the maximum completion time criteria. The algorithm explored only two end nodes out of the twelve hundred and ninety six possible

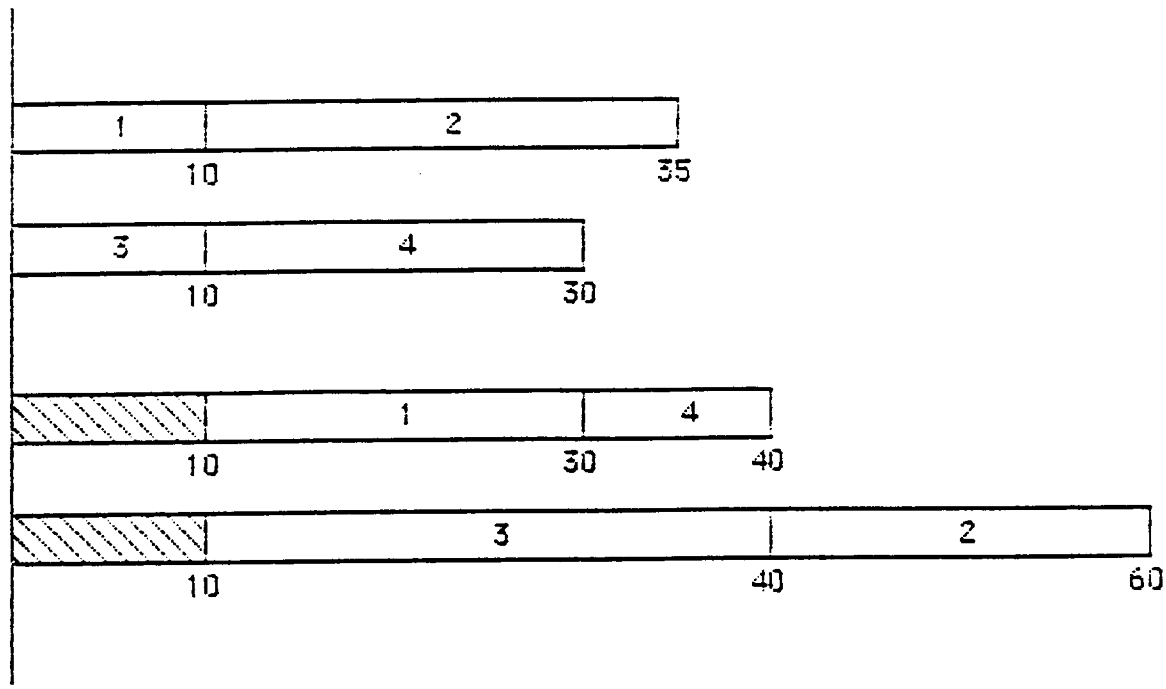

FIGURE 6B.5 NONDELAY SCHEDULE FOR MINIMIZING MAKESPAN IN A FLOW SHOP WITH MULTIPLE PROCESSORS.

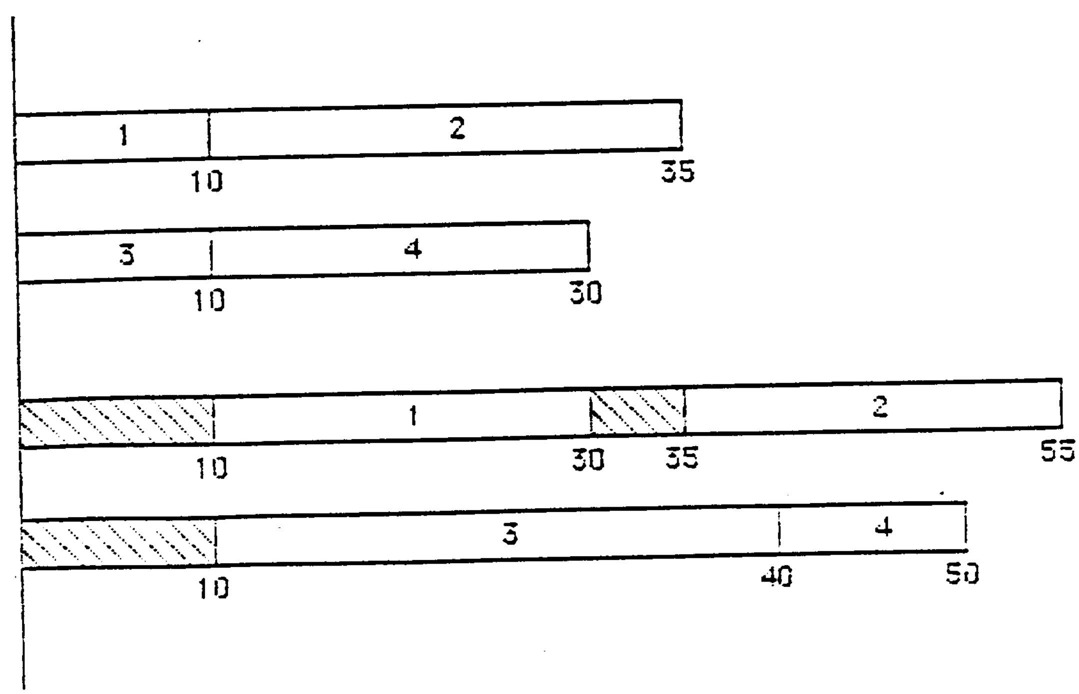

FIGURE 6B.6 OPTIMAL SCHEDULE FOR MINIMIZING MAKESPAN IN A FLOW SHOP WITH MULTIPLE PROCESSORS.

nodes for the example problem. The CPU time on an IBM-XT for solving this problem is 0.69 seconds. Some other computation time data for various problem sizes is presented in Table 6B.2. The processing time data for the study is generated from a uniform distribution between 0 and 100.

10.0 FURTHER EXTENSIONS

The computational algorithm developed in this research uses the bounding procedures to discard the nodes which are known to have a lower bound larger than a complete solution. Given the exponential nature of the problem, the algorithm is observed to be consistently working with a fair amount of computation speed. Nevertheless, in order to improve the computation speed for large size problems, the elimination rules developed in this research can be used in conjunction with the lower bounds. For example, if jobs q and r follows an arrangement resembling the pattern b or c of Figure 6B.7 as a part of a branching node of the tree at stage 1. Then due to Theorem 6B.1, for any regular measure of performance a branching node which contains any one of the three patterns d, e, and f, will be eliminated from further consideration at stage 2. Similarly because of Corollary 6B.2, for the makespan criteria, the elimination of nodes containing one of the patterns d, e, or f, will result at stage m if the branching tree at stage m-1 has a partial node resembling a pattern a, b, or c. In similar

TABLE 6B.2 COMPUTATION TIME RESULTS OF THE BRANCH AND BOUND ALGORITHM.

PROBLEM SIZE			SAMPLE SIZE	NUMBER OF POSSIBLE END NODES	AVERAGE COMP. TIME ON IBM-XT	AV. NO. OF END NODES SEARCHED
n	m	M_j, j=1,m.				
					HR:MN:SEC	
4	2	2,2	10	1.296×10^3	00:00:00.60	1.6
4	5	2,2,2,2,2	10	6.047×10^7	00:01:16.27	4.5
6	2	2,2	10	3.240×10^6	00:00:42.52	8.0
6	3	2,2,2	10	5.832×10^9	00:06:12.70	10.9
6	5	2,2,3,2,2	10	1.260×10^{16}	12:07:19.76	22.6
8	2	3,3	10	1.992×10^{10}	00:06:46.91	8.4

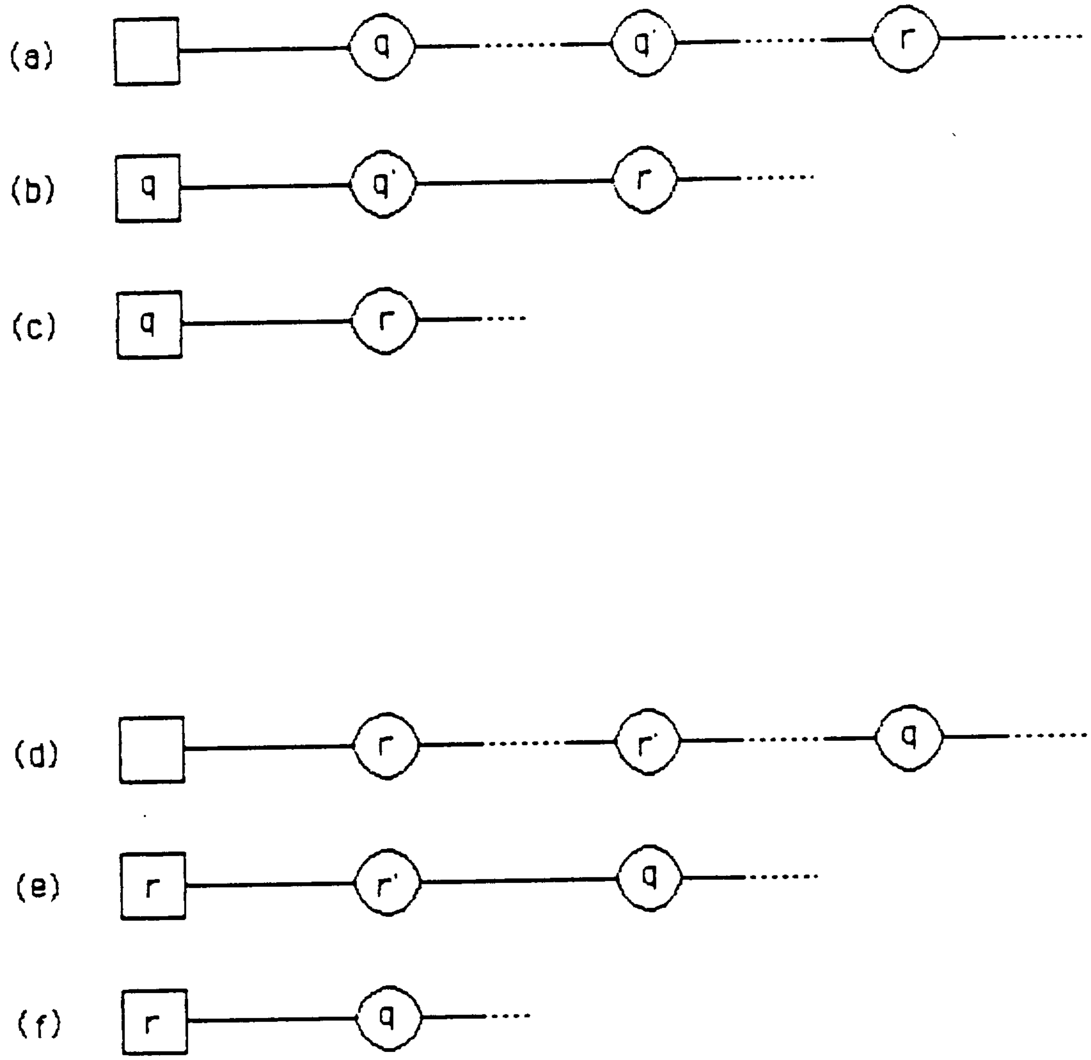

FIGURE 6B.7 PARTIAL PATTERNS OF BRANCHING NODES.

pursuit, Theorem 6B.2 and other elimination rules developed here will further reduce the search tree.

The branch and bound algorithm developed here for optimizing the makespan of a FSMP can also be used to optimize other measures of performance. The only difference will be in computation of lower bounds of the branching nodes. Lower bounds for the measures of performance other than makespan, however, are not known to exist at this time and research is recommended in such direction.

Further efforts can be expanded for the development of useful heuristics, particularly for a combinatorial problem like the one of a FSMP. To begin with, there are several variations of branch and bound algorithms which have been usefully employed in the literature. Some of these variations are discussed here and they can be used for an adaptation to the branch and bound algorithm for a FSMP.

- o Set up a counter on the number of nodes (and/or end nodes) to be fully explored by the algorithm.
- o Set up a percentage improvement index on each new feasible solution generated by the algorithm. This means that if the percentage improvement from one feasible solution to the other is less than that index, further exploration is stopped.
- o A combination of the above two variations, etc.

The adaptation of such simple variations is expected to improve the computation speed of the branch and bound algorithm developed here for a FSMP. However, this increased speed will not come without a cost, which is the possibility of missing an optimal solution.

11.0 SUMMARY

The flow shop with multiple processors scheduling problem has been studied before by several researchers. The solution methodologies available in literature ranges from the mathematical formulation for the small size problems to heuristic algorithms for large size problems. This paper presents a branch and bound algorithm and solution method for the optimal solution of the makespan problem of a FSMP. The computational results of the algorithm are fairly encouraging for solving problems of medium size. Several extensions are also proposed for optimal or near optimal solution methods of large scale problems.

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APPENDIX VI C

HEURISTIC PROGRAMMING STUDY OF A FLOW SHOP WITH MULTIPLE PROCESSORS

1.0 INTRODUCTION

Scheduling procedures are generally classified as either localized or centralized. The advantage of local rules is in that they are based upon the most up to date information on the state of the machine or work center. Queuing or dispatch rules are examples of such scheduling procedures. The advantage of centralized rules is that they consider a larger picture. Mathematical and heuristic algorithms, such as Johnson's algorithm for the two machine flow shop (Baker 1974) or the Smith Panwalker and Dudek heuristic algorithm for the general flow shop (Smith et al. 1975) are examples of centralized rules. The drawback of overlooking the global picture in localized rules is overcome by using centrally drawn schedules. However, the price of centralization is paid in the form of computation or response time, which in turn predicates the reaction to changes in the system.

Due to the limitation of computation time for even a problem of modest size, localized rules sometimes provide the only way of finding a feasible solution to the problem. Furthermore, the use of heuristic programming investigation

through the method of computer simulation for localized scheduling using dispatch or queueing rules furnishes an alternate to the algebraic or probabilistic methods. The effect of dispatching procedures in simulation models is very difficult to describe, nevertheless, the study of such heuristic rules contributes to a valuable understanding of the system for different measures of performance.

The purpose of this heuristic programming study is to investigate the behavior of two regular measures of performance, mean flow time and makespan, in a FSMP. The scheduling or dispatch rules used in the study are localized rules. However, the priorities for scheduling the jobs, in the simulation model, are established dynamically at each stage of processing.

2.0 SIMULATION MODELING

Computer simulation involves experimentation on a computer based model of some system. The simulation model in such an evaluation, often seeks to duplicate the behavior of the system in order to demonstrate the likely effect of various policies. One of the main strengths of this approach is that it abstracts the essence of the problem and reveals its underlying structure. This provides insight into cause-and-effect relationships within the system. If it is possible to construct the mathematical model which is both a reasonable representation of the actual situation and

solvable in a manageable amount of time, then the analytical technique is of course superior to simulation. However, the large scale FSMP scheduling problems are so complex that to carry out fully integrated analyses, the analytical techniques cannot be usefully utilized. In such situations, even though it may still be relatively complicated to perform computer simulation, often it may be the only practical approach to the problem.

The first step in the heuristic programming study of the simulation model of the FSMP scheduling problem is to build a model. The model under study is that of a static FSMP for which all jobs are simulated to arrive at the beginning of each simulation run. The processing times of the jobs are generated from a uniform distribution between 0 and 100. Further, all jobs are assumed to be available at the beginning of simulation, i.e., the arrival time of all jobs is zero. The system works on nondelay schedules with no preemption allowed. Whenever a waiting line develops in front of a processing stage, a dynamic queuing discipline is used to set the priority. The job with the highest priority in the queue is scheduled next whenever a processor becomes available. The analysis for each set of processing data is repeated for all priority rules and the measures of performance are recorded and contrasted. Although in real life it is possible to have an unequal number of parallel processors at each stage, nevertheless, in order to limit the study, only an equal number of parallel processors is

investigated in this research. The flow diagram of the simulation model of a FSMP is presented in Figure 6C.1.

The model is run for one hundred data sets for various number of jobs and processing stages, and a given number of parallel processors at each stage. For each simulation data set, the performance of priority rules is measured for two measures of performance, namely the mean flow time and the makespan. The best rule for the data set under consideration is selected for each criteria and the performance score of the priority rule responsible for obtaining the best solution of each performance measure is increment by one. In case of ties, the scores of all priority rules in the tie are increment. Naturally this would imply that the sum of the scores on all priority rules could be greater than one hundred. Also, the mean flow time and the makespan are recorded for the priority rules and the averages over one hundred simulation runs are reported.

Many simulation studies have been performed mostly for the job shop cases, see the RAND studies (Convey et al. 1967), Baker (1974), Panwalker and Iskander (1977), Buzacott and Shanthikumar (1985), O'Grady and Harrison (1985), Scudder and Hoffmann (1985), Kim (1987), Russell et al. (1987), Vepsalainen and Morton (1987), and Yao and Kim (1987). In studies involving makespan and mean flow time criteria, the local scheduling rules mentioned below are the most commonly studied. The list of rules studied here is

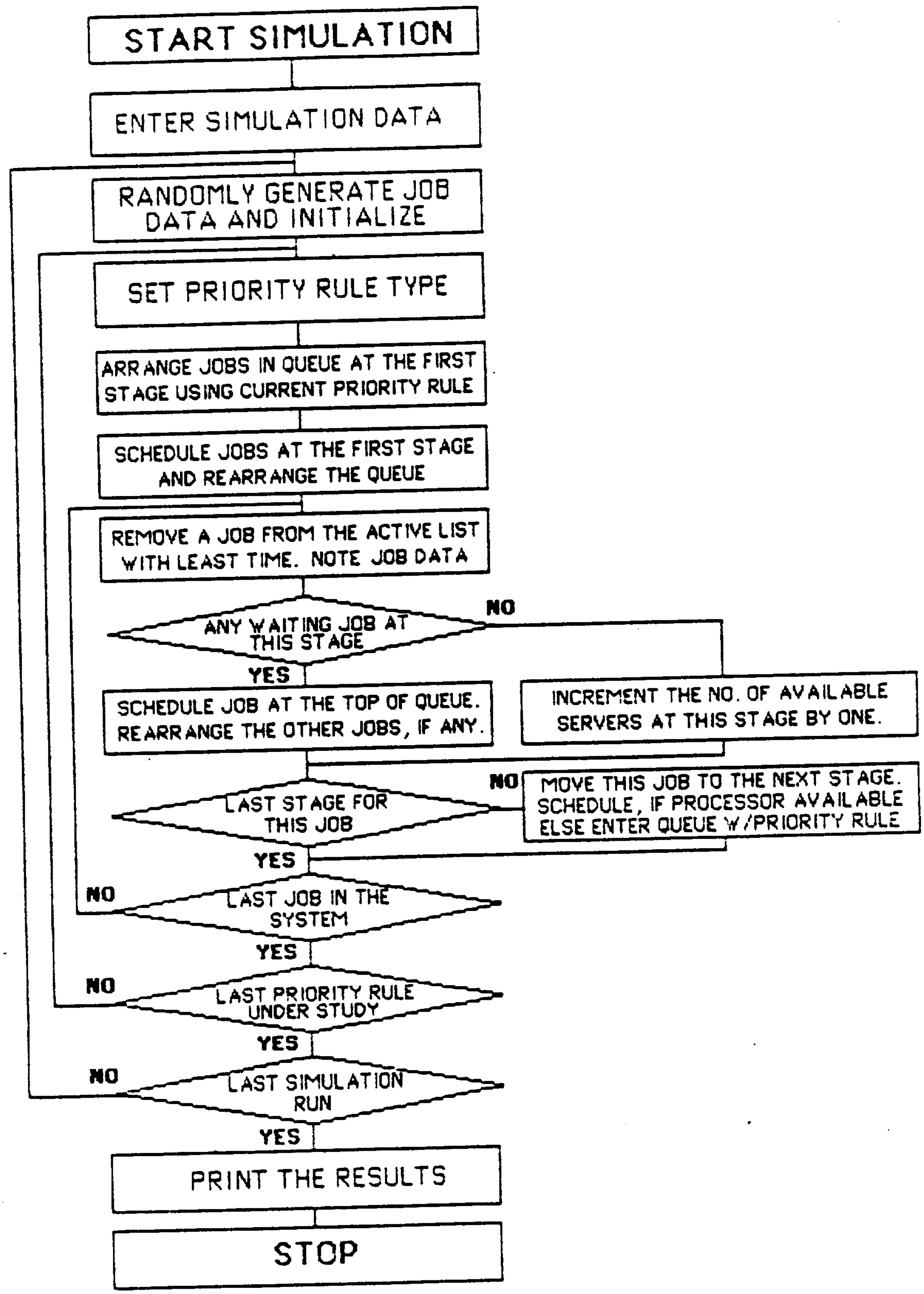


FIGURE 6C.1. FLOW DIAGRAM OF SIMULATION OF A FSMP PROBLEM.

certainly not exhaustive. Also, there are other priority rules which are not applicable to the FSMP problem. The priority or heuristic rules considered for the simulation study of the FSMP scheduling problem are listed below:

- FIFO (First In First out): Select the operation of the job which was first to enter the queue at that stage.
- LIFO (Last In First Out): Select the operation of the job which last entered the queue for service.
- SPT (Shortest Processing Time First): Select the operation with the minimum processing time.
- LPT (Largest Processing Time First): Select the operation with the largest processing time.
- MTWF (Most Total Work First): Select the operation with the maximum total work in the flow shop.
- LTWF (Least Total Work First): Select the operation with the minimum total work in the flow shop.
- MWRF (Most Work Remaining First): Select the operation associated with the job having the most work remaining.
- LWRF (Least Work Remaining First): Select the operation associated with the job having least work remaining.
- RANDOM (Random): Select the operation at random.

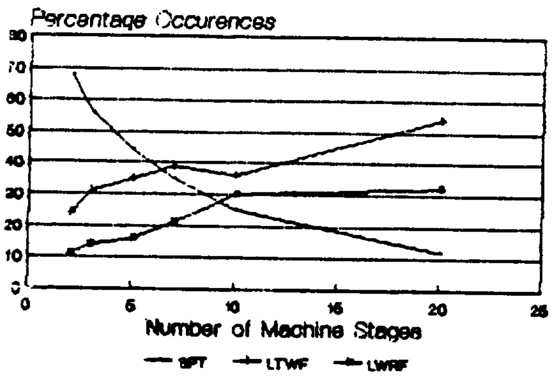
3.0 PRESENTATION OF FINDINGS

As discussed before, the mean flow time and the makespan criteria for a FSMP, were studied for the number of occurrences of the best solution among the rules considered and the average value of the parameters over the simulation runs. The number of times the best solution was achieved is considered as an indicator of the performance of the rule, while the average value of the measures represent the overall performance.

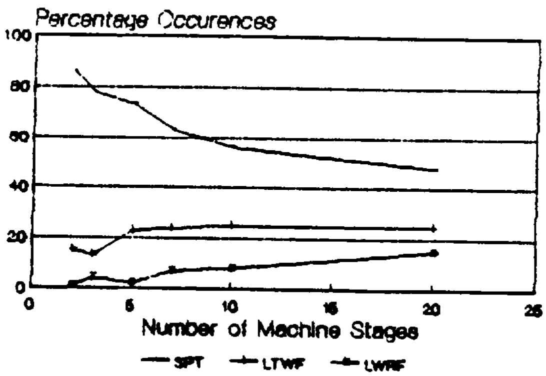
Six sets of jobs, and six sets of machine stages for each job set, were studied for 1-5, 7 and 10 parallel processors at each stage of processing for all of the priority rules.

3.1 MEAN FLOW TIME CRITERIA

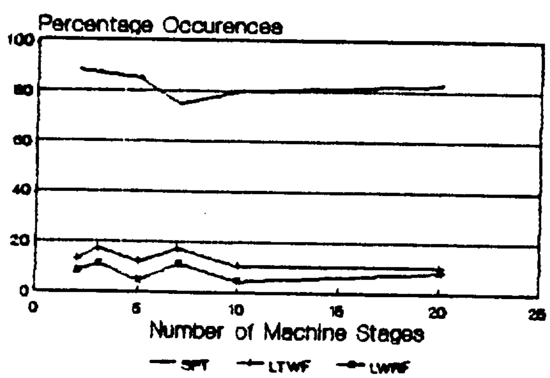
Figures 6C.2 through 6C.7 exhibit the performance in terms of the number of occurrences of the three most significant priority rules considered, namely the SPT, LTWF and LWRF, for the mean flow time criteria. The number of jobs, the number of machine stages and the number of parallel processors at each stage are the three variables studied in these figures. For each figure one of these variables is kept constant, while the other is varied for each one of the four graphs. The third variable is studied as an independent variable for the dependent variable of the



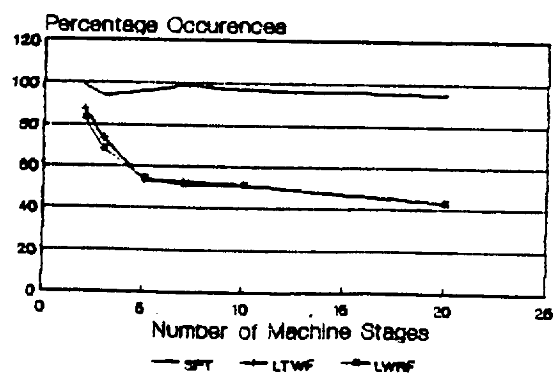
n=10; # of Processors at each stage = 1.



n=10; # of Processors at each stage = 3.

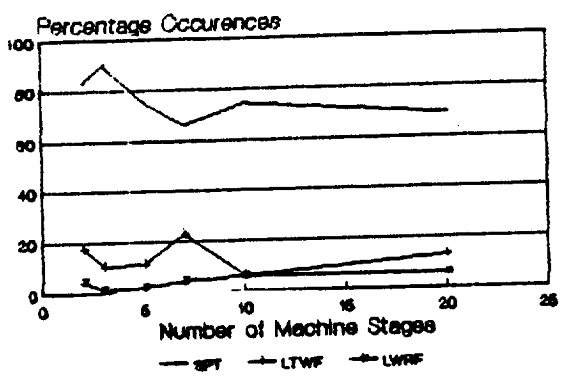


n=10; # of Processors at each stage = 5.

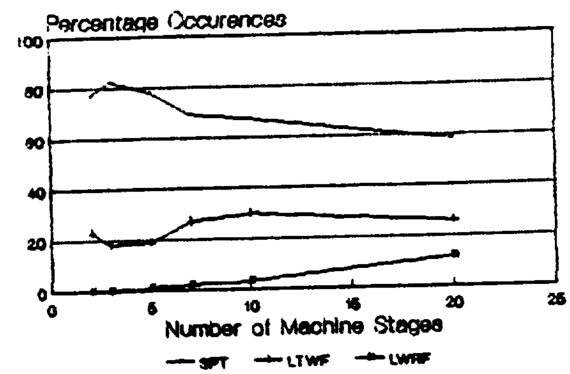


n=10; # of Processors at each stage = 7.

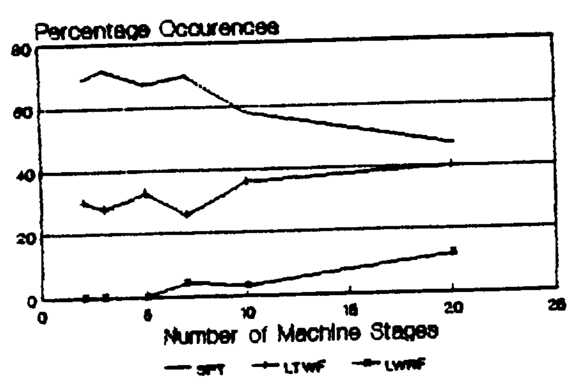
FIGURE 6C.2. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.



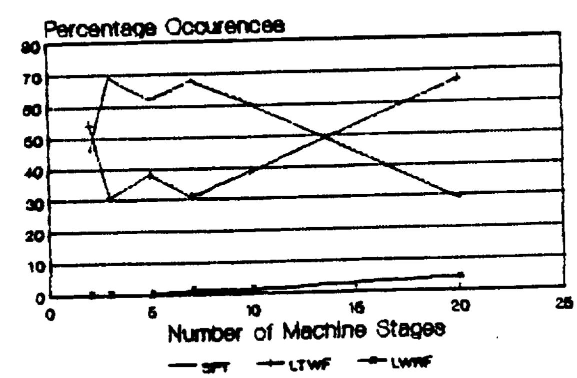
n=10; # of Processors at each stage = 4.



n=20; # of Processors at each stage = 4.



n=30; # of Processors at each stage = 4.



n=50; # of Processors at each stage = 4.

FIGURE 6C.3. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.

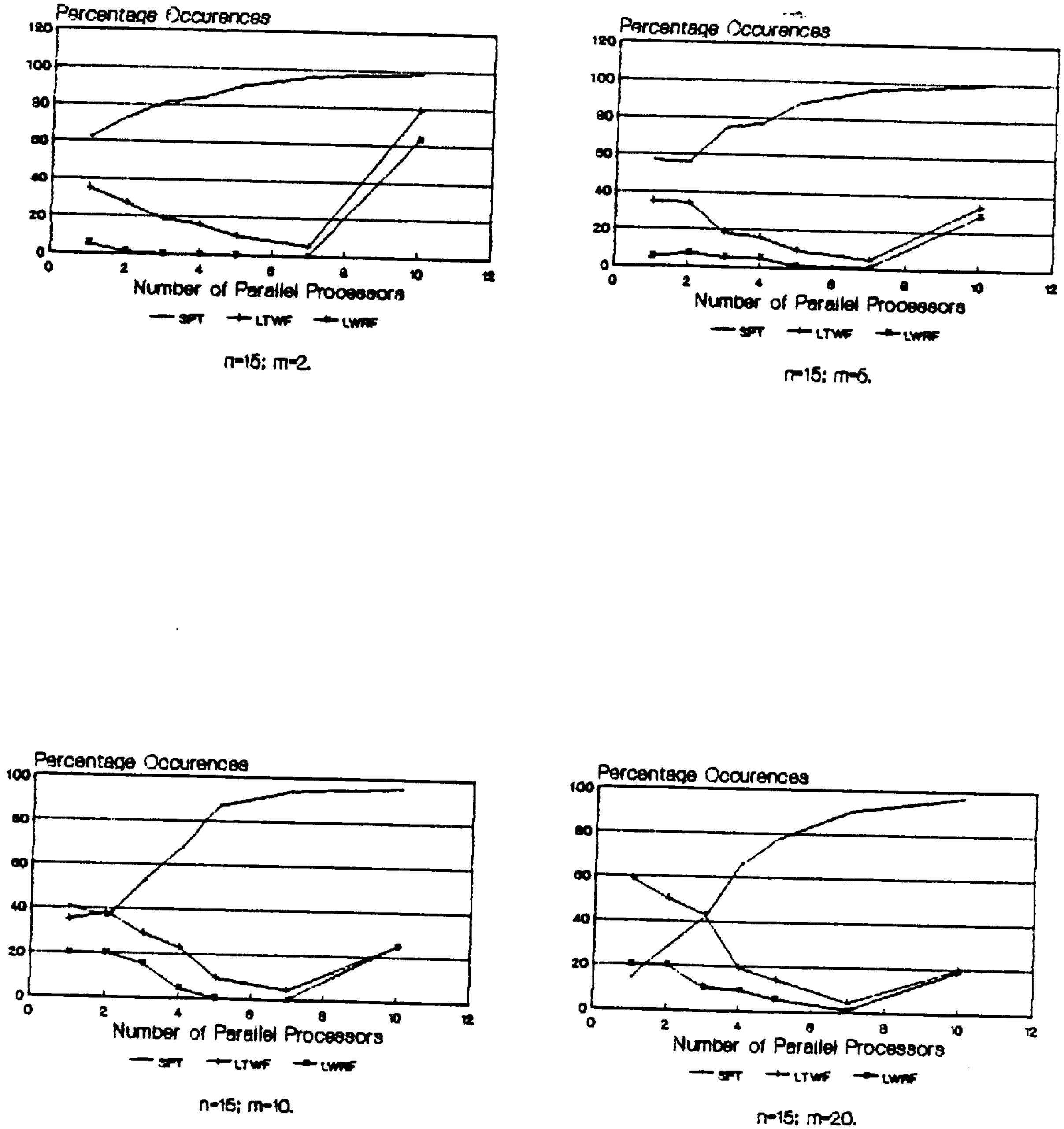


FIGURE 6C.4. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.

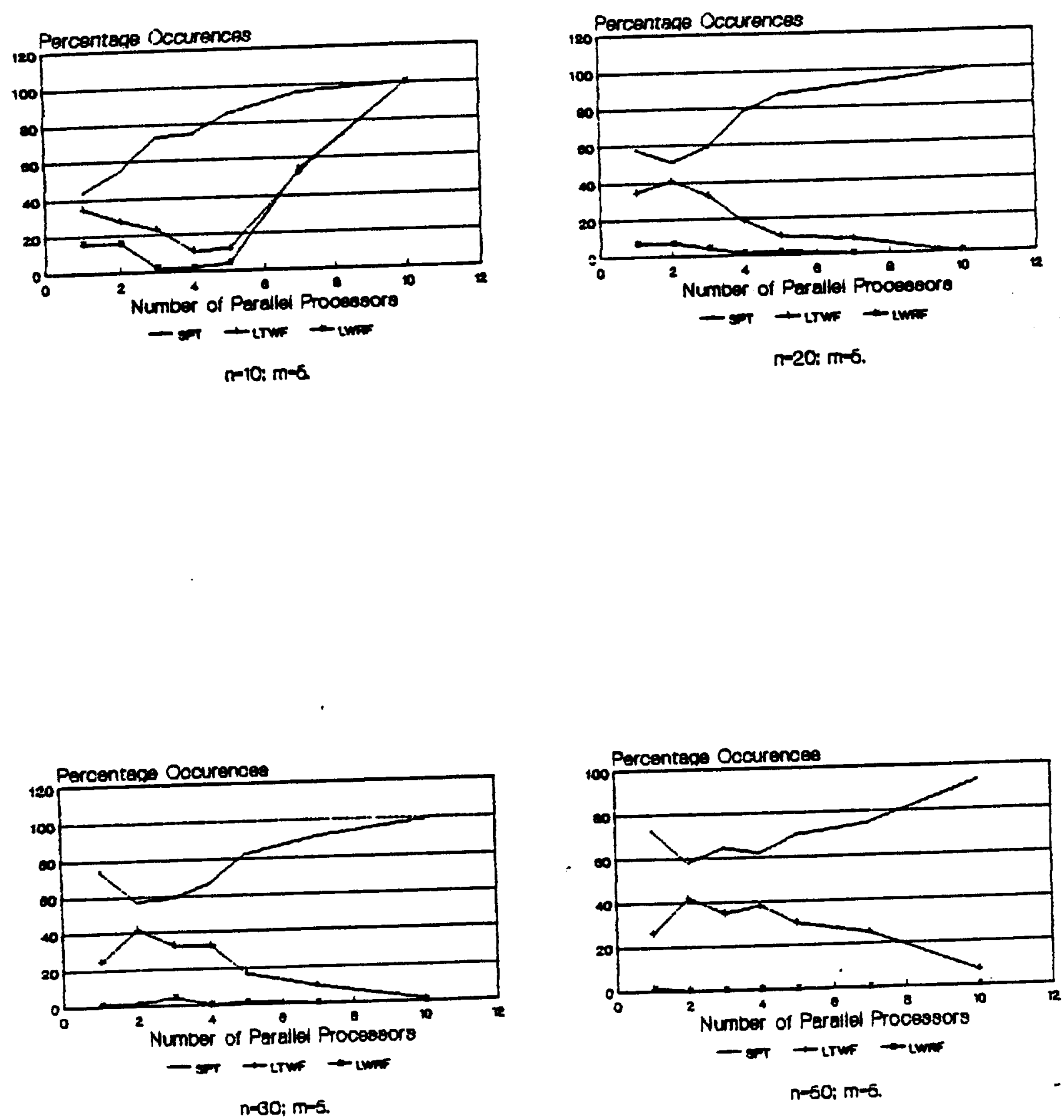
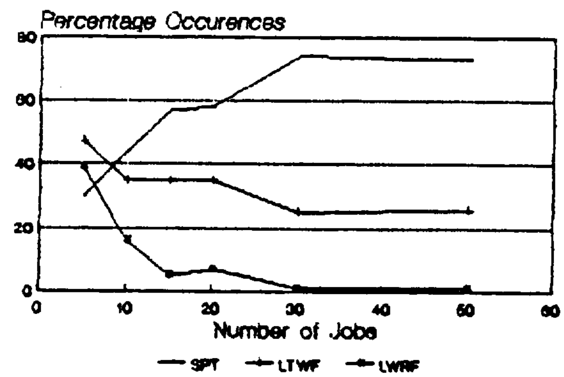
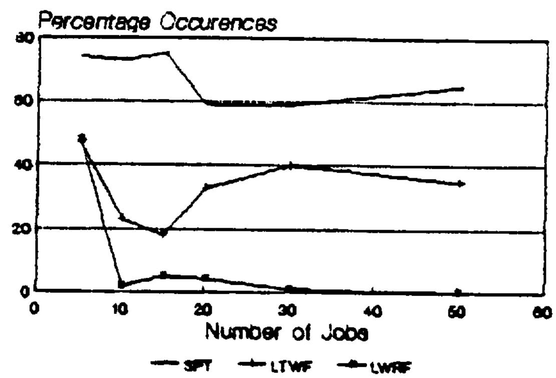


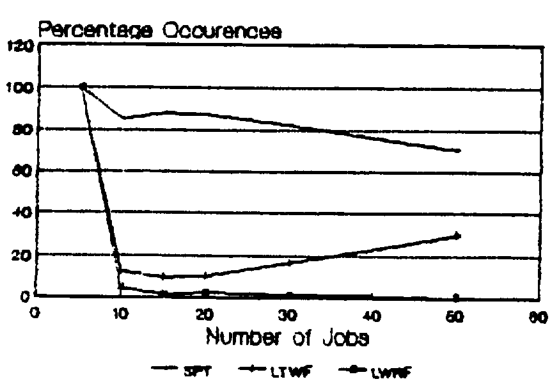
FIGURE 6C.5. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.



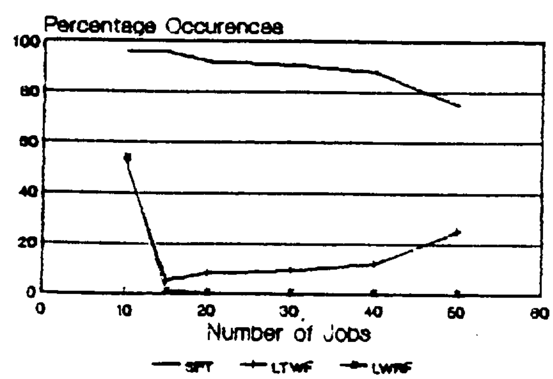
m=6; # of Processors at each stage = 1.



m=6; # of Processors at each stage = 3.

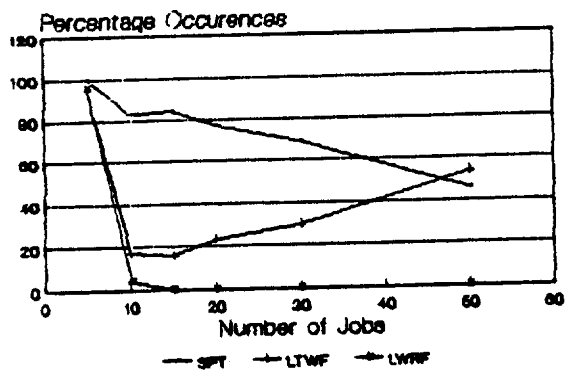


m=6; # of Processors at each stage = 5.

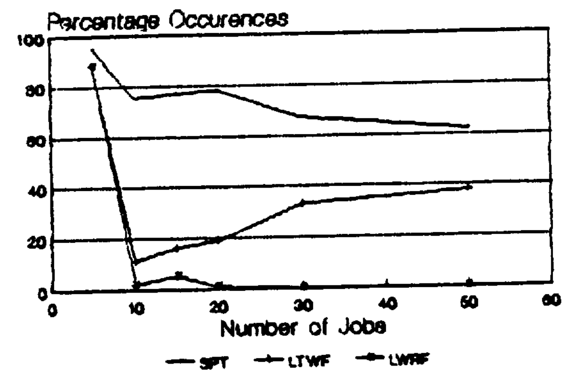


m=6; # of Processors at each stage = 7.

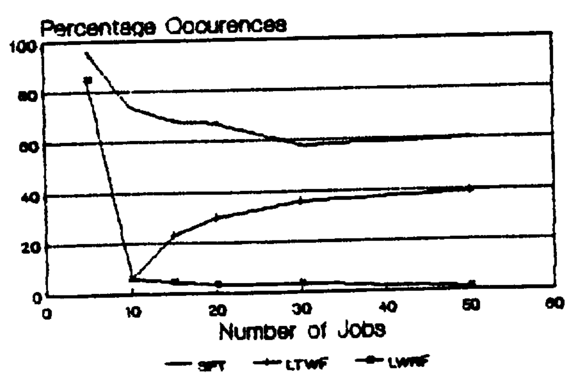
FIGURE 6C.6. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.



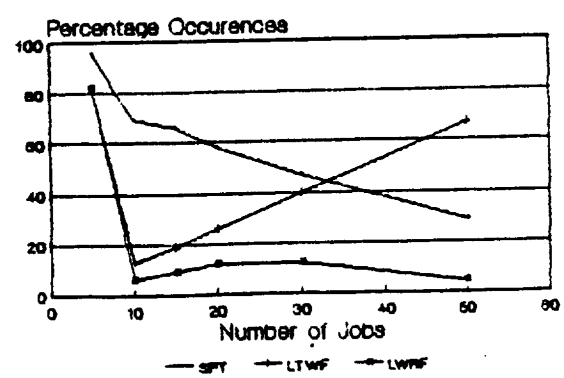
m=2; # of Processors at each stage = 4.



m=5; # of Processors at each stage = 4.



m=10; # of Processors at each stage = 4



m=20; # of Processors at each stage = 4

FIGURE 6C.7. MEAN FLOW TIME RESULTS OF SIMULATION STUDY.

number of occurrences of the priority rules under study in each graph.

Figure 6C.2 shows the performance of the three rules in terms of the number of occurrences with respect to the number of machine stages, for a fixed number of jobs and parallel processors. The four graphs of the figure are for ten jobs, and 1, 3, 5 and 7 parallel processors, respectively, at each stage of processing. Figure 6C.3 is similar to Figure 6C.2, except that the number of parallel processors is a constant with a value of four, and the graphs are for 10, 20, 30 and 50 jobs, respectively, as the other constant for each graph. Similarly, Figures 6C.4 and 6C.5 show the performance of the three rules in terms of the number of occurrences with respect to the number of parallel processors for a fixed number of jobs and machine stages. The four graphs of the Figure 6C.4 are for fifteen jobs, and 2, 5, 10 and 20 machine stages, respectively. In Figure 6C.5, the performance of 10, 20, 30 and 50 jobs, respectively, is observed against the number of parallel processors for five machine stages case. Finally, Figures 6C.6 and 6C.7 show the performance of the same three rules in terms of the number of occurrences, with respect to the number of jobs for a given number of parallel processors and machine stages. The four graphs of the Figure 6C.6 are observed for the changes in the performance of rules with respect to the number of jobs for five machine stages, and 1, 3, 5 and 7 parallel processors, respectively. While,

the graphs of Figure 6C.7 are observed for the number of jobs as a variable for 2, 5, 10 and 20 machine stages, respectively, and four parallel processors at each stage.

Further, Table 6C.1 shows the percentage decrease in the mean flow time, or the relative superiority in the performance of the SPT as compared to the RANDOM priority rule for the mean flow time criteria.

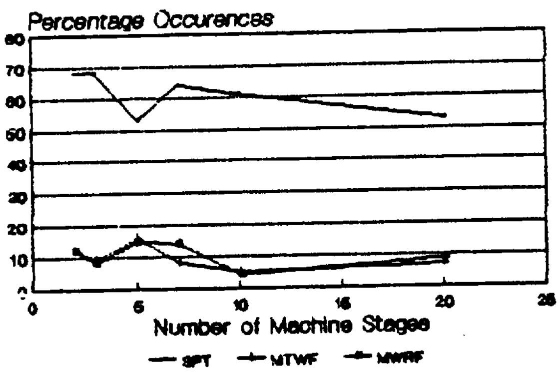
3.2 MAKESPAN CRITERIA

Some of the results of the simulation study for the makespan criteria are exhibited in Figures 6C.8 through 6C.10. The performance in terms of the number of occurrences of the three most significant priority rules, namely SPT, MTWF and MWRF, for the makespan criteria is presented graphically in these figures. The method of presentation of the graphs is similar to the one adopted for the mean flow time criteria.

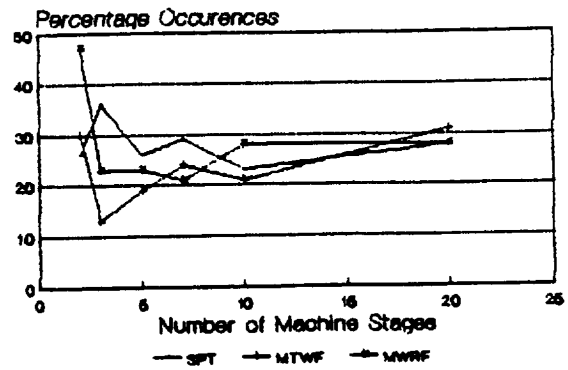
Figure 6C.8 shows the performance of the three rules in terms of the number of occurrences, with respect to the number of machine stages for a fixed number of jobs and parallel processors. The four graphs of the figure are for ten jobs, and 1, 3, 5 and 7 parallel processors, respectively, at each stage of processing. Similarly, Figure 6C.9 shows the performance of the three rules in terms of the number of occurrences with respect to the

TABLE 6C.1 PERCENTAGE DECREASE IN THE MEAN FLOW TIME OF THE SPT RULE WITH RESPECT TO THE RANDOM RULE.

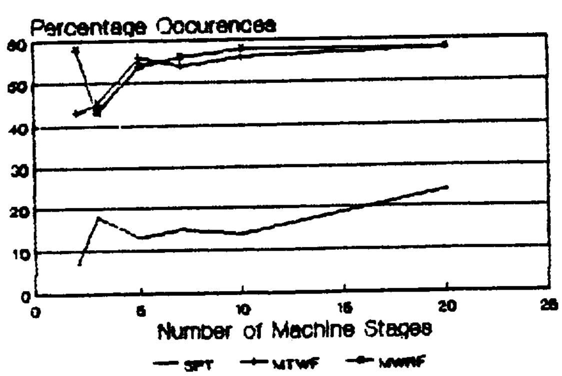
n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	20.5	11.2	4.35	0.78	0
5 x 3	18.0	9.94	3.00	0.45	0
5 x 5	12.3	5.96	2.20	0.31	0
5 x 7	8.58	4.33	1.34	0.19	0
5 x 10	5.37	3.63	1.49	0.17	0
5 x 20	3.93	1.71	0.71	0.07	0
10 x 2	27.1	20.3	16.1	11.3	7.76
10 x 3	20.8	17.3	13.6	8.95	5.59
10 x 5	14.6	13.4	8.44	5.19	3.04
10 x 7	12.6	10.3	7.14	4.45	2.43
10 x 10	7.90	5.21	4.77	3.00	1.58
10 x 20	4.65	4.41	2.51	1.55	0.80
15 x 2	27.6	22.9	21.3	18.4	14.5
15 x 3	23.4	21.4	16.9	12.8	11.0
15 x 5	16.9	14.2	11.7	8.87	7.18
15 x 7	14.2	10.0	8.70	7.32	6.17
15 x 10	9.93	8.17	6.89	5.34	3.73
15 x 20	4.69	5.04	4.48	2.79	1.98
20 x 2	28.6	26.8	22.6	21.1	17.4
20 x 3	22.3	22.0	19.2	16.5	13.6
20 x 5	16.4	15.2	13.6	10.9	9.55
20 x 7	15.1	13.1	10.3	9.10	7.08
20 x 10	11.1	10.5	8.53	6.52	5.59
20 x 20	5.80	5.38	4.74	3.59	2.83
30 x 2	27.9	26.1	24.8	24.7	21.6
30 x 3	24.0	21.9	21.3	19.4	17.6
30 x 5	18.8	16.7	15.4	14.2	12.9
30 x 7	15.4	13.7	12.3	11.1	10.1
30 x 10	11.9	10.4	9.74	8.38	7.82
30 x 20	7.36	5.79	5.84	5.10	4.02
50 x 2	27.5	26.9	26.7	24.4	25.2
50 x 3	21.4	21.2	21.2	20.5	19.9
50 x 5	17.9	16.9	16.8	15.8	15.4
50 x 7	15.1	14.5	13.2	13.4	12.4
50 x 10	12.7	11.9	10.4	10.2	9.83
50 x 20	7.97	7.17	6.25	5.51	6.22



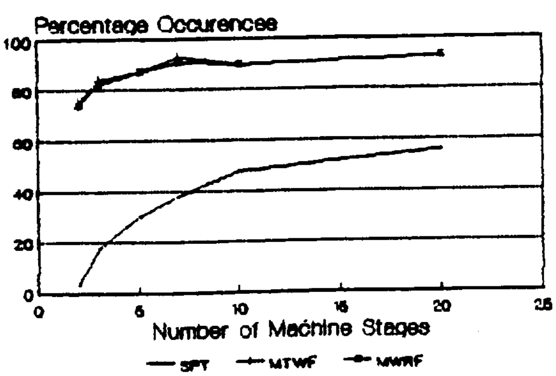
n=10; # of Processors at each stage = 1.



n=10; # of Processors at each stage = 3.

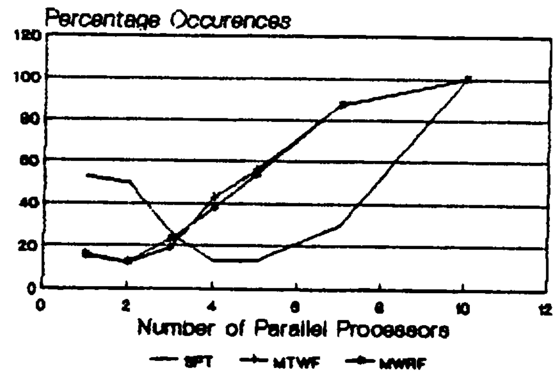


n=10; # of Processors at each stage = 5.

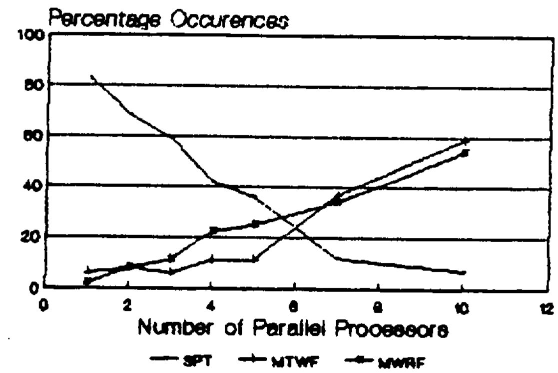


n=10; # of Processors at each stage = 7.

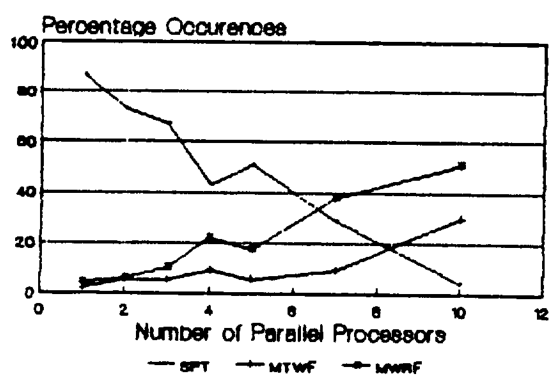
FIGURE 6C.8. MAKESPAN RESULTS OF SIMULATION STUDY.



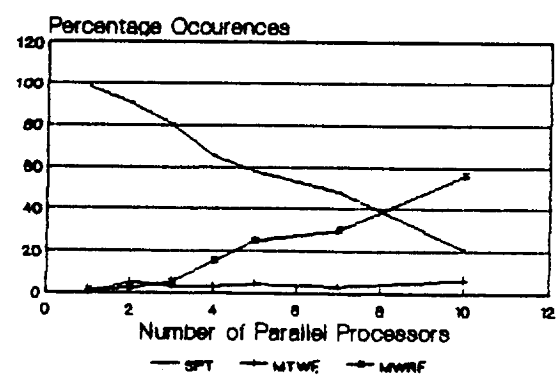
n=10; m=5.



n=20; m=5.

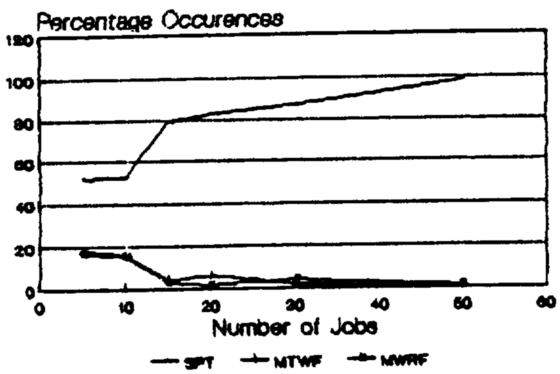


n=30; m=5.

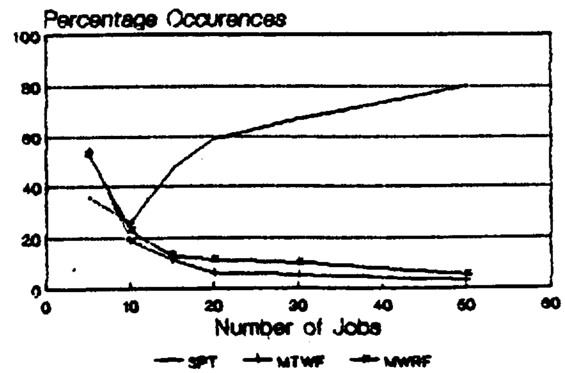


n=50; m=5.

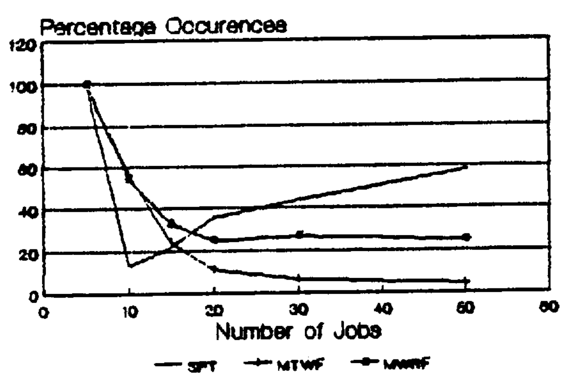
FIGURE 6C.9. MAKESPAN RESULTS OF SIMULATION STUDY.



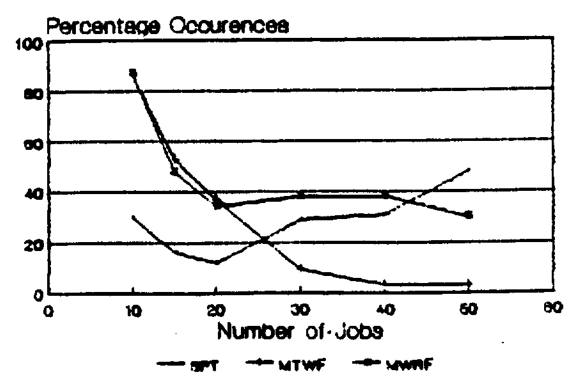
m=5; # of Processors at each stage = 1.



m=5; # of Processors at each stage = 3.



m=5; # of Processors at each stage = 5.



m=5; # of Processors at each stage = 7.

FIGURE 6C.10. MAKESPAN RESULTS OF SIMULATION STUDY.

number of parallel processors for a given number of jobs and machine stages. The four graphs of the figure are examined for 10, 20, 30 and 50 jobs, respectively, and five machine stages. Finally, Figure 6C.10 shows the performance of the same three rules in terms of the number of occurrences with respect to the number of jobs for a given number of parallel processors and machine stages. The observed graphs in this case are for five machine stages, and 1, 3, 5 and 7 parallel processors, respectively, at each stage.

Additionally, Table 6C.2 shows the percentage decrease in the makespan, or relative superiority in the performance of the SPT rule as compared to the RANDOM priority rule, while Tables 6C.3 and 6C.4 demonstrates the same relationship for the MTWF and MWRF priority rule, respectively.

4.0 OBSERVATIONS AND CONCLUSIONS OF SIMULATION STUDY

The simulation study of the FSMP problem is a limited study in the sense that only two criteria are studied for the static representation. The results obtained provides general guidelines for the selection of the priority rules. The SPT priority rule is observed to be consistently superior to all other rules studied in the research for the mean flow time criteria. However, in the study of the makespan criteria, there is no clear superior and the study

TABLE 6C.2 PERCENTAGE DECREASE IN THE MAXIMUM FLOW TIME OF THE SPT RULE WITH RESPECT TO THE RANDOM RULE.

n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	7.34	0.04	-1.6	-2.1	0
5 x 3	11.0	6.30	-0.8	-1.1	0
5 x 5	11.0	4.61	0.54	-1.3	0
5 x 7	7.30	1.30	0.80	-0.2	0
5 x 10	5.16	2.14	-0.0	0.14	0
5 x 20	3.67	2.44	0.56	-0.0	0
10 x 2	7.78	4.55	3.09	-1.7	2.20
10 x 3	9.96	5.49	5.35	2.64	0.65
10 x 5	9.51	6.21	3.91	2.68	0.86
10 x 7	9.18	6	2.91	1.12	0.16
10 x 10	7.22	3.85	2.63	1.49	0
10 x 20	5.43	3.99	2.38	0.93	0.81
15 x 2	6.32	5.11	2.31	2.17	2.03
15 x 3	10.0	8.68	5.17	2.91	2.04
15 x 5	12.1	8.60	5.71	4.20	2.78
15 x 7	9.48	7.31	4.80	2.90	2.70
15 x 10	8.81	5.33	4.48	2.58	2.13
15 x 20	4.68	5.17	4.43	1.57	1.14
20 x 2	6.62	5.91	3.31	2.47	0.59
20 x 3	10.0	6.98	6.31	2.78	3.46
20 x 5	9.95	9.64	7.32	6.56	3.33
20 x 7	10.9	8.57	5.21	5.47	4.32
20 x 10	10.0	8.44	5.99	3.68	1.59
20 x 20	5.81	4.89	3.73	2.61	1.80
30 x 2	5.00	5.11	4.03	3.48	3.13
30 x 3	9.98	6.93	6.01	4.83	3.85
30 x 5	10.8	8.06	7.16	5.12	4.51
30 x 7	11.7	9.20	8.21	5.67	5.74
30 x 10	9.44	6.61	7.55	5.12	4.51
30 x 20	7.22	6.14	4.90	3.43	2.65
50 x 2	4.45	3.74	4.25	2.31	3.88
50 x 3	7.13	6.83	5.32	4.72	4.03
50 x 5	9.97	8.56	8.75	6.39	5.57
50 x 7	10.1	9.98	8.35	6.33	6.25
50 x 10	9.85	8.71	7.69	7.52	6.40
50 x 20	8.13	6.53	5.60	5.03	4.14

TABLE 6C.3 PERCENTAGE DECREASE IN THE MAXIMUM FLOW TIME OF THE MTWF RULE WITH RESPECT TO THE RANDOM RULE.

n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	-0.8	5.28	4.29	2.68	0
5 x 3	0.18	6.26	3.40	2.42	0
5 x 5	2.44	3.19	2.11	0.96	0
5 x 7	-0.6	0.58	3.17	1.27	0
5 x 10	0.21	1.27	1.65	1.06	0
5 x 20	-0.6	2.62	1.53	0.41	0
10 x 2	0.28	2.13	6.34	6.41	10.5
10 x 3	-0.1	0.57	3.00	6.85	7.32
10 x 5	0.63	1.11	2.51	7.27	6.21
10 x 7	1.42	1.47	2.89	4.76	3.98
10 x 10	-0.2	0.09	3.51	4.28	2.85
10 x 20	0.95	1.68	2.73	2.71	2.25
15 x 2	1.00	1.97	3.58	5.76	7.16
15 x 3	-0.0	1.16	1.75	1.39	5.84
15 x 5	1.01	0.29	1.10	2.96	6.13
15 x 7	-0.5	0	-0.5	2.26	4.93
15 x 10	-0.3	-0.3	1.55	3.38	4.84
15 x 20	-0.2	0.74	2.64	3.54	3.82
20 x 2	0.82	1.59	2.97	3.80	4.13
20 x 3	2.51	0.77	1.78	2.54	4.14
20 x 5	-1.0	0.46	1.78	1.53	1.65
20 x 7	0.66	0.25	-1.0	0.39	3.39
20 x 10	0.36	1.01	0.61	1.66	2.62
20 x 20	0.64	-0.2	1.08	3.24	3.98
30 x 2	0.31	1.54	2.57	3.22	4.31
30 x 3	0.36	-0.2	0.73	2.25	1.75
30 x 5	0.87	0.20	0.11	0.86	1.53
30 x 7	0.02	0.70	0.63	0.31	1.81
30 x 10	0.03	-1.0	0.28	1.70	1.52
30 x 20	-0.1	1.24	0.43	0.68	2.08
50 x 2	0.87	0.84	1.33	1.83	2.61
50 x 3	0.48	0.98	1.34	1.66	1.34
50 x 5	0.58	0.75	0.38	0.04	0.76
50 x 7	-0.1	0.47	0.82	-0.1	0.48
50 x 10	0.32	0.85	0.01	0.49	0.74
50 x 20	0.41	0.17	0.24	0.49	1.49

TABLE 6C.4 PERCENTAGE DECREASE IN THE MAXIMUM FLOW TIME OF THE MWRF RULE WITH RESPECT TO THE RANDOM RULE.

n x m	NUMBER OF PARALLEL PROCESSORS				
	1	2	3	4	5
5 x 2	-0.8	5.71	4.55	2.68	0
5 x 3	0.14	6.38	3.49	2.42	0
5 x 5	2.45	3.62	1.96	0.96	0
5 x 7	-0.8	0.39	3.15	1.27	0
5 x 10	0.38	1.49	1.67	1.06	0
5 x 20	-0.5	2.95	1.54	0.41	0
10 x 2	0.28	2.80	8.55	8.78	12.0
10 x 3	0.06	1.50	5.08	7.73	7.99
10 x 5	0.73	1.46	3.96	7.24	5.97
10 x 7	1.60	2.02	3.11	4.64	4.02
10 x 10	-0.0	0.01	3.82	4.55	2.94
10 x 20	0.92	1.19	2.57	2.67	2.18
15 x 2	1.00	2.60	4.91	8.32	10.5
15 x 3	0.12	2.14	3.73	4.24	8.88
15 x 5	1.04	0.54	1.96	4.65	6.46
15 x 7	-0.1	0.44	-0.6	3.18	4.79
15 x 10	-0.3	-0.6	1.63	3.33	5.22
15 x 20	-0.2	0.62	2.52	3.22	3.65
20 x 2	0.82	2.08	4.10	5.84	7.11
20 x 3	2.59	1.46	3.55	5.01	7.72
20 x 5	-1.0	1.01	2.67	3.87	3.42
20 x 7	0.80	0.82	-0.2	1.50	3.54
20 x 10	0.67	1.05	1.11	1.93	2.97
20 x 20	0.74	-0.2	1.02	3.15	4.10
30 x 2	0.31	1.78	3.31	4.53	6.33
30 x 3	0.49	0.19	1.84	4.44	5.42
30 x 5	1.06	0.66	1.12	2.75	3.70
30 x 7	0.12	0.86	1.61	1.03	3.55
30 x 10	0.03	-0.7	1.41	1.93	1.84
30 x 20	-0.0	0.76	0.28	0.77	2.04
50 x 2	0.87	1.03	1.75	2.75	3.84
50 x 3	0.33	1.48	2.34	2.96	3.37
50 x 5	0.65	1.11	1.55	1.30	2.97
50 x 7	-0.1	1.08	1.47	1.18	1.72
50 x 10	0.58	0.80	0.53	0.37	1.50
50 x 20	0.39	0.28	-0.0	0.46	1.35

is more or less unconvincing for the percentage improvement in the makespan of contending priority rule over the RANDOM priority rule. Further observations and conclusions on the two measures of performance are summarized below in the following subsections.

4.1 MEAN FLOW TIME CRITERIA

The performance of the SPT priority rule has been observed to be consistently superior to all other rules studied in this simulation research for minimizing the mean flow time criteria. The notable challenge to this rule came from the LTWF rule and somewhat from the LWRF rule. Indeed for the large size problems, the superiority of SPT is clearly demonstrated. For the small size problems, the distinction is not very clear specially when the number of jobs approaches the number of parallel processors at each stage. This behavior should naturally be expected for a limited queuing takes place at each stage of processing, thereby increasing the possibility of reaching the best solution by random sequencing. Other observations include:

- The performance of the SPT in terms of the number of occurrences deteriorates with the increase in the number of stages for the same number of jobs and parallel processors. A similar trend is also noticed in the percentage improvement of the mean flow time using the SPT over the RANDOM priority rule.

- o The performance of the SPT sequencing rule in terms of the number of occurrences improves with the increase in the number of parallel processors for the same number of jobs and machine stages. Quite surprisingly, the percentage improvement of the mean flow time using the SPT, over the RANDOM priority rule decreases for the same situation, most likely because of the availability of alternate routes.
- o The performance of the SPT priority rule in terms of the number of occurrences declines by the increase in the number of jobs for the same number of machine stages and parallel processors. However, the trend is inconclusive in terms of the percentage decrease in the average value of the mean flow time of the SPT over the RANDOM priority rule.
- o For $(M_j / n \times m) > 0.01$, the SPT priority rule is generally a good choice for $M_j > 1$. Also, for $(M_j / n \times m) < 0.01$, the LTWF priority rule becomes a good contender.

4.2 MAKESPAN CRITERIA

The results of the simulation study for the makespan criteria are not as apparent as that for the mean flow time. The SPT rule, however, is distinctively superior to all other sequencing rules considered in the case of a pure flow shop, i.e., $M_j = 1$ for all j. It also performs better than

others when the number of jobs to the number of parallel processors ratio is large and when the number of stages is large. In other situations, the MWRF rule dominates others with the MTWF rule following closely (as opposed to LWRF and LTWF rules for the mean flow time criteria). Surprisingly, the LPT rule, which heuristically gives the best makespan in the parallel machines scheduling, never became a viable contender except in the situation when the number of jobs approaches the number of parallel processors. Even in such situations, the results compared marginally or worst than the ones for the RANDOM priority rule. Some of the other observations include:

- The performance of the SPT sequencing rule in terms of the number of occurrences improves steadily with the increase in the number of jobs, however, it sharply decreases with the increase in the number of parallel processors at each stage.
- The performance of the SPT priority rule in terms of the percentage decrease in the average makespan over the RANDOM rule, decreases with the increase in the number of parallel processors at each stage.
- The performance of the MTWF and MWRF priority rules in terms of the number of occurrences improves steadily with the increase in the number of parallel processors and decreases sharply with the increase in the number of jobs.

- o The performance of the MTWF and MWRF priority rules is not significantly better than the RANDOM rule in terms of the average makespan. This is in spite of the fact that these rules dominates the RANDOM priority rule in terms of the number of occurrences.

5.0 FURTHER EXTENSIONS

There are other measures of performance such as mean tardiness and maximum tardiness which have not been studied in this research. A similar simulation study of a FSMP is recommended for such criteria. However, for additional measures of performance, such as the ones mentioned above, other appropriate priority rules must also be considered. In addition, some hybrid priority rules may be developed and studied further for a similar or extended study of the FSMP scheduling problem.

Moreover, the essence of simulation study is more closely captured in a dynamic study of the problem. Therefore, a dynamic study of a FSMP is recommended for mean flow time, mean tardiness, maximum tardiness, and other measures of performance. Such a study will provide a closer look at the large scale scheduling problem of a FSMP.

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APPENDIX VI D

PRIDICTION OF NSTS FLIGHT RATE

EXECUTIVE SUMMARY
MASTERS PROJECT OF CAPT. R. A. RONCACE
PREDICTION OF NSTS FLIGHT RATE
BY JLH 6 OCT 88

The purpose of this paper is to develop a methodology to predict the flight rate of the shuttle based on the premise that JSC can support anything that KSC can fly. To this end the historical processing times at KSC are used as the basis for the predictions. The paper uses a two pronged approach to determine flight rate. One method used is to apply a Weibull distribution to historical times and then run a simulation for 50 sets of 50 flows. Another is to assume that a learning curve is in effect and to look at flights 41 through 60. In both methods, the first orbiter flight in 81 is ignored and the remaining 24 processing flows are separated into 17 normal flows and 7 anomalies (page 6 or Table 1).

Several caveats are made: the effects of the Challenger accident are not taken into account and neither are facility conflicts at KSC or launch window constraints. Additionally, the following assumptions are made in the work: The SCA and MLP are always available, each flight is 7 days in duration, a return from Edwards takes 5 days, 50% of the landings are at Edwards, and anomalies amount to 1/4 of the total flows.

The results are shown in the following table:

Learning Curve Results

work days/week	days/year	optimistic	pessimistic
7 days/week	365	23.4 flts/yr	14.2 flts/yr
6 days/week	312	20.0 flts/yr	12.1 flts/yr
5 days/week	260	16.7 flts/yr	10.1 flts/yr
5/week + 10 holidays	250	16.0 flts/yr	9.7 flts/yr

Statistical Results

days/year	95 % confidence interval	90% confidence interval
365	14.94 to 14.77	14.93 to 14.76
312	12.77 to 12.62	12.76 to 12.63
260	10.64 to 10.52	10.63 to 10.53
250	10.23 to 10.11	10.22 to 10.12

The conclusions of the paper (page 22-23) are worth reading in their entirety. The main conclusion is, because of the optimistic nature of the higher numbers, that NSTS will have "only marginal capability to meet the planned maximum sustained flight rate of 14 flights per year, and only then if significant learning curve progress can be sustained and/or work schedules allowing few holidays and down weekends are used over long periods of time."

INDE 6398

MASTERS PROJECT

PREDICTION OF NATIONAL SPACE TRANSPORTATION SYSTEM FLIGHT RATE BY ANALYSIS OF SPACE SHUTTLE PROCESSING FLOW EXPERIENCE

BY

ROBERT A. RONCACE

A paper submitted in partial fulfillment

of the requirements for the degree of

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I. Introduction.

I.A. Purpose.

The purpose of this paper is to develop and apply a methodology to predict the flight rate of the National Space Transportation System (NSTS).

I.B. Background.

Since the loss of the Space Shuttle Challenger in early 1986, it has been generally realized in NASA and the aerospace industry that Shuttle flights would be in short supply in the years to come. Flight assignments for major payloads have therefore been strictly controlled based on National priority. Department of Defense missions and National science missions have first priority. Virtually all commercial payloads with the capability of flying to space on an expendable booster have been forced to seek such an alternative to the Shuttle.

As the mix of payloads has changed, so has the relative importance of schedule slippage. Delays in the launch of DoD missions may handicap our national technical means of intelligence gathering and arms control verification. Delayed science missions mean slow downs and cost increases for many programs, including, but not limited to, the US Space Station. With such national interests at stake it is critically important for an operational space launch capability to meet it's advertised schedule, or conversely, to only advertise a schedule that can be met.

The flight rate of the National Space Transportation System (NSTS) is literally the number of Space Shuttle flights flown in a particular period of time. The time period of interest here is the Fiscal year, since this is the planning time unit normally used by NASA for long range planning.

Despite the Space Shuttle's many notable accomplishments, the flight rate of the NSTS has never reached it's intended maximum. The original NSTS Program Plan predicted as many as 48 flights per year, eventually. This estimate was reduced several times during the development and early years of NSTS operations. By November 1985 the maximum expected flight rate had been reduced to 24 flights per year, to be achieved in Fiscal year 1989 [1]. In the nearly five years of NSTS operations (up through the Challenger accident) there have been only 25 Space Shuttle missions launched. The most flights launched in one year was ten. This occurred in the calendar year immediately preceding the Space Shuttle Challenger accident and included the last Challenger launch.

Current plans call for a quick buildup, once flight operations resume in late 1988, to 10 flights in FY90 [2], increasing to a maximum sustained flight rate of 14 per year in FY94 [3]. This flight rate assumes delivery of the fifth orbiter in 1991 to replace Challenger. Continuous upgrades to the Shuttle processing facilities at Kennedy Space Center (KSC) are also planned throughout the period

since these facilities were never considered adequate to support the planned flight rate. Given the past inability to meet the program plan flight rate and the current sensitivity to delays in the flight schedule, a method of making a realistic estimate of potential NSTS flight rate must be developed.

The flight rate predictions made in this paper are based on the assumption that preparation of the flight hardware controls the possible flight rate. The process of preparing the Space Shuttle hardware for flight is accomplished at the Kennedy Space Center (KSC) at Cape Canaveral, Florida. Although the flight planning activities performed at the NASA L.B. Johnson Space Center in Houston, Texas, require more time than the hardware preparation at KSC, the activities at JSC are not seen as the "long pole in the tent."

Johnson Space Center's products are primarily in the areas of payload and flight planning, shuttle flight software production and astronaut training. These activities are believed to be sufficiently flexible to support whatever hardware preparation schedule KSC could achieve.

The premise of this paper is that analysis of the past flight preparation experience data from KSC should allow a practical estimation of the achievable future NSTS flight rate. The sequence of activities done at KSC on the Space Shuttle Orbiter, it's Boosters, and External Tank (collectively called a "stack" once mated together) to

prepare each mission is called a processing flow. Every Space Shuttle mission is processed through the same ground facilities in the same order. These facilities are, in order, the: Orbiter Processing Facility (OPF), Vehicle Assembly Building (VAB), and the Launch Pad (Pad). Figure 1 illustrates the Space Shuttle Processing Flow.

This paper explores two methods of making NSTS flight rate estimates, both incorporating simplified simulations of the Shuttle processing flows. The first utilizes statistical prediction of processing times. To do this, appropriate statistical distributions will be fit to the cumulative Shuttle processing experience. These statistical distributions will then be used to randomly generate additional Shuttle hardware processing flows to simulate the system. The mean flight rate of the the NSTS will be calculated from the results of the simulation.

The second analysis method predicts processing times by the application of learning curve theory. In this method, the cumulative Shuttle processing experience will again be examined, but this time in chronological order. The presence of learning curve effects will be visible in reduced flow processing times as experience increases. Learning curves will be fit to this data to determine the learning rate. Once the learning rate is known (and assuming the rate remains constant) the theoretical processing time of any Shuttle mission may be calculated. The local mean theoretical processing time may be calculated by examining several flows prior to and after

SPACE SHUTTLE PROCESSING FLOW

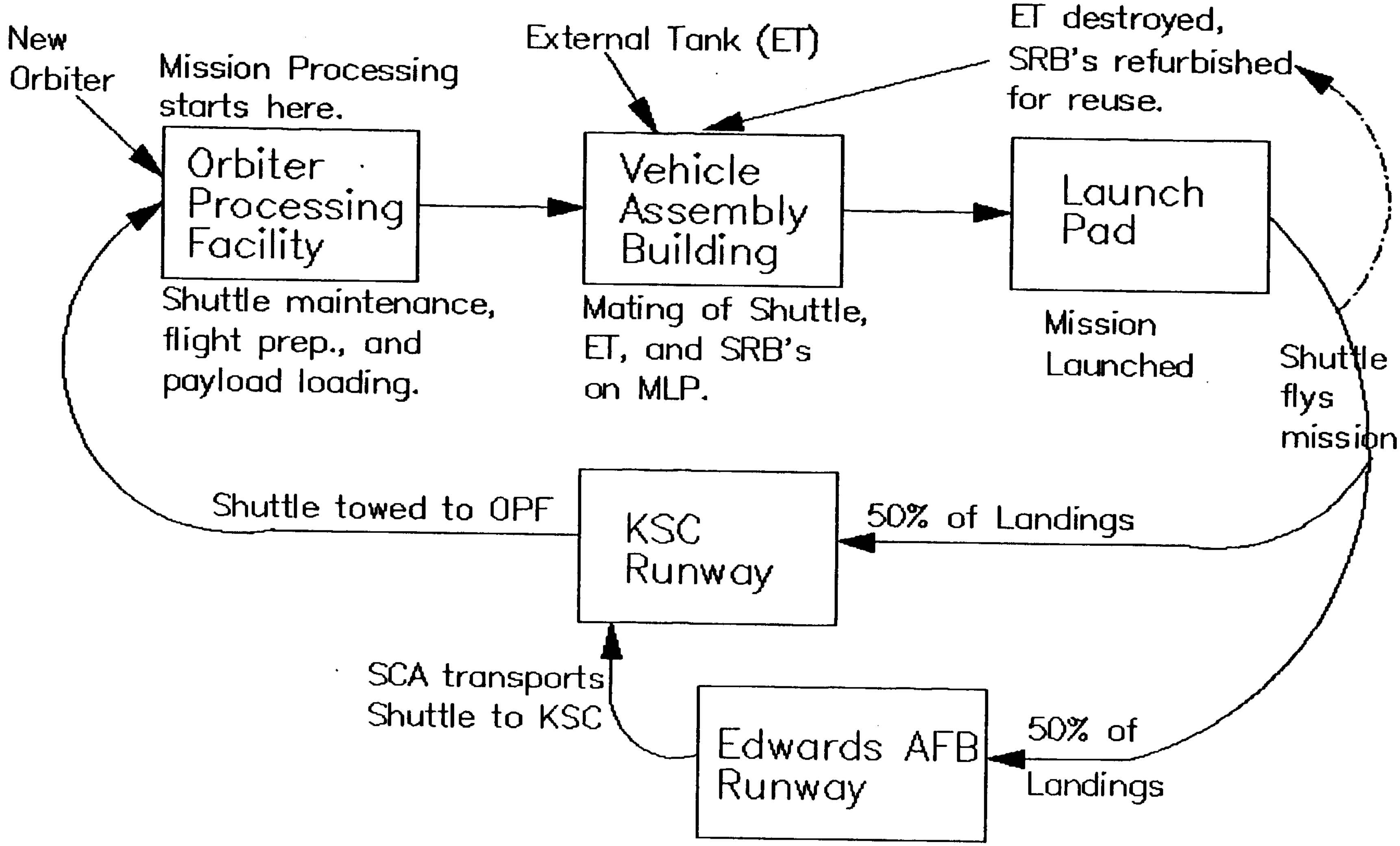

Figure 1

the one of interest. And from the mean flow processing time the mean flight rate may be calculated.

Though initially straightforward, the above methods of analysis rapidly become complicated when the actual flow processing experience is examined. The reason for the complication lies in the simple fact that no two Shuttle missions or processing flows are alike. Though the facilities and their processing order are always the same, that is not to say that exactly the same processing actions occur each time the Shuttle is prepared to fly.

From one processing flow to the next the actions accomplished in these facilities are tailored to meet the needs of the mission being prepared and the maintenance requirements of the particular Shuttle orbiter vehicle. Though they outwardly appear identical, the three remaining Shuttles are not the same, either in equipment or capability. Perhaps the most glaring example, Columbia, the first Shuttle, has an empty weight approximately 8,000 pounds greater than her sisters, Discovery and Atlantis. Columbia's extra weight is caused by the presence of additional structure and flight instrumentation found to be unnecessary for the later Shuttles after the Columbia's test program was completed.

The above is just the most obvious example, but many other less obvious, though no less important, physical differences exist between these highy complex, yet largely hand made spacecraft. These differences directly influence the work needed to prepare the shuttles for flight.

Therefore, flight rates may not be extrapolated from the results of a single processing flow.

I.C. Normal Flows and Anomaly Flows:

The first Space Shuttle flight occurred during April, 1981, using the Orbiter Vehicle "Columbia" (all of the Shuttles are known as "Orbiter Vehicles" (OV); Columbia is assigned the designator: OV-102). The first mission is not considered in this analysis because the types and quantities of preparation for the first mission were unique compared to the other missions. The first mission's processing flow was uniquely long even compared to the first flows of the other orbiters: "Challenger"; OV-099, "Discovery"; OV-103, and "Atlantis"; OV-104.

Of the remaining 24 Shuttle processing flows, seven have been identified as anomalies. They are considered anomalies because their processing times were unusually long compared to the trends presented by the other flows at the time. These anomalous flows will undergo the same analysis as the 17 normal flows but will be treated separately. The seven anomalies include: the other three "first flows" (one each for the other three orbiters), the first flow for OV-102 after overhaul, two Spacelab flows (complicated missions and the first of their kind), and mission number 2 (which had unique inspection requirements associated with the processing flow). Table 1 shows the normal and anomaly flows and the processing times data experienced in the facilities at KSC [4].

Table 1

KSC SHUTTLE PROCESSING FLOW DATA
(Workdays)

"Normal Flows"

Mission Seq #	STS- No.	Orbiter OV-	FACILITY PROCESSING TIMES OPF	VAB	Pad	Total	Flight Dur	Notes
3	3	102	55	12	30	97	8.00	%
4	4	102	41	7	29	77	7.05	
5	5	102	48	9	45	102	5.09	
7	7	99	34	5	21	60	6.10	
8	8	99	26	4	25	55	6.05	
10	41-B	99	52	6	22	80	7.97	
11	41-C	99	31	4	18	53	6.99	
13	41-G	99	53	5	22	80	8.22	
14	51-A	103	34	5	17	56	7.99	
15	51-C	103	31	5	20	56	3.06	
16	51-D	103	53	5	15	73	7.00	
18	51-G	103	37	7	14	58	7.07	
19	51-F	99	39	5	31	75	7.95	&
20	51-I	103	27	7	22	56	7.10	
22	61-A	99	35	4	14	53	7.03	&
23	61-B	104	27	4	15	46	6.88	
25	51-L	99	30	5	28	63		@

"Anomaly Flows"

Mission Seq #	STS- No.	Orbiter OV-	FACILITY PROCESSING TIMES OPF	VAB	Pad	Total	Flight Dur	Notes
1	1	102	531	33	104	668	2.26	$
2	2	102	99	18	70	187	2.26	**
6	6	99	123	6	115	244	5.02	*
9	9	102	82	12	34	128	10.32	&
12	41-D	103	123	15	72	210	6.04	*
17	51-B	99	88	12	32	132	7.01	&
21	51-J	104	84	14	34	132	4.07	*
24	61-C	102	101	8	34	143	6.09	#

Key to Notes:

% All Flight Durations are given in calendar days.
& Spacelab mission.
@ Flight duration N/A.
$ OV-102 first flow - not used in this analysis.
** OV-102 second flow.
* First flow for this Orbiter.
# First flow for OV-102 after overhaul.

References:
- Processing Flow Times; Ref #4.
  Flight Durations; Ref #10.

I.D. Caveats and Assumptions.

Before beginning this study several additional caveats and assumptions must be stated:

Caveat 1: This study does not examine the effects of the additional procedures which have been incorporated into the Shuttle processing flow since the Space Shuttle Challenger accident. Those additions will have the effect of increasing the time required to process the Space Shuttle for flight. Thus the results of this study will likely prove to be optimistic compared with the current capabilities of the NSTS.

Caveat 2: The simulations employed in this study do not account for facility conflicts at KSC. Extended delays between missions due to launch window constraints are also not accounted for. Both of these considerations would have the effect of reducing the potential flight rate, making the results of the simulations optimistic.

Assumption 1: It was assumed for this study that the Shuttle Carrier Aircraft (SCA) and the Mobile Launcher Platform (MLP) were always available when needed. The SCA is a modified Boeing-747 aircraft capable of carrying the Space Shuttle piggyback. Whenever the Shuttle returns from a space mission to a landing at Edwards Air Force Base or White Sands Space Harbour, the SCA is used to ferry the Space Shuttle back to KSC for maintenance and processing. Only one SCA is currently available, although another is on order. Loss or breakdown of the SCA could disrupt the Shuttle flight schedule since at least 50-percent of future

Shuttle missions are expected to land at Edwards AFB.

The MLP is a massive four-tracked land crawler used to move the fully assembled Shuttle "stack" from the VAB to the launch Pad. The trip only requires about one day to complete, but the MLP is fully occupied in the VAB for mating (stacking) of the External Fuel Tank, Solid Rocket Boosters, and the Shuttle, for as much as several weeks before the stack is moved to the Pad. Two MLP's are now available and a third is on order, but loss or breakdown of one of the existing MLP's would delay the flight schedule.

Assumption 2: Several assumptions were made for the simulations concerning the duration of flight, the fraction of the landings to be made at KSC, and the time required to ferry an orbiter to KSC from an Edwards AFB landing. The flight duration was assumed to be seven days for all flights. In fact, the flight duration is a function of many factors, only the more obvious of which are: orbit inclination, orbit altitude, landing site selection, payload requirements, weather considerations, and problems experienced during the mission. Perhaps the only definite thing that can be stated is the mission duration will not be exactly what is planned. Since approximately seven days was the most common flight duration of the current mission experience (see Table 1), and seven days is the standard mission duration for planning purposes, we use this value for our simulation.

Like the situation with the flight duration, the time to return the orbiter to KSC from an Edwards AFB landing

will have it's own unique distribution. Five days is the planned time so we will use this value directly, on the assumption that deviations will be normally distributed about the mean and will have no effect over the long term.

The 50-percent fraction of the landings expected to occur at Edwards AFB is based on the current NSTS long range program plan. But all landings will be made at Edwards AFB for the first several missions after resumption of flight activities in late 1988. Therefore the application of these simulations to early flights will not have taken into account the expected greater than 50-percent landings at Edwards AFB. The simulations results may yield an optimistic flight rate for this reason.

Assumption 3: Anomaly flows were assumed to occur at a ratio of approximately one-quarter of the total number of flows, or 1 anomaly : 3 normal flows. The actual ratio experienced was 7 anomaly : 17 normal flows, or 1 : 2.43. Recent NSTS management decisions have reduced the number of relatively simple commercial deployment missions compared to the number of complicated Spacelab and other science missions. However, the future of this policy is certainly subject to change. What is known is that the new, replacement orbiter is expected to be delivered for it's first flow in 1991 and all of the orbiters will periodically experience long processing flows to allow overhauls, inspections, and modifications. Thus the assumed ratio may be a slightly optimistic assumption and may yield optimistic flight rate results.

II. Flight Rate Estimation Using Statistical Distributions.

II.A. Assessment of Correlation Factors Between Facilities.

The purpose of this section is to establish whether the processing times for the several facilities are independent, or if there is some causal relationship between the facilities. If the OPF, VAB, and Pad facilities have processing times with no relationship among them it will be possible to fit statistical models to the facility time histories and randomly generate flow times for the individual facilities. Otherwise it will be necessary to simulate the process using some statistical model of the total flow (the sum of the times for the three facilities for each flow) process time histories.

Figures 2 and 3 are scatter plots of the KSC facility time histories showing the individual facilities compared with their next serial partner in the flow. That is, OPF vs VAB and VAB vs Pad. These data are displayed in the original pairings as they occurred. Although there is significant scattering of the data some relationships appear to exist for the Normal Flows.

Figure 2a displays OPF vs VAB processing time for the normal flows. Though not easily defined, there appears to be a relationship causing VAB processing time to increase as OPF processing time increases. A similar trend is apparent implying increased Pad processing time as VAB processing time increases, as shown in Fig 2b.

For the Anomaly flows no such trends are readily

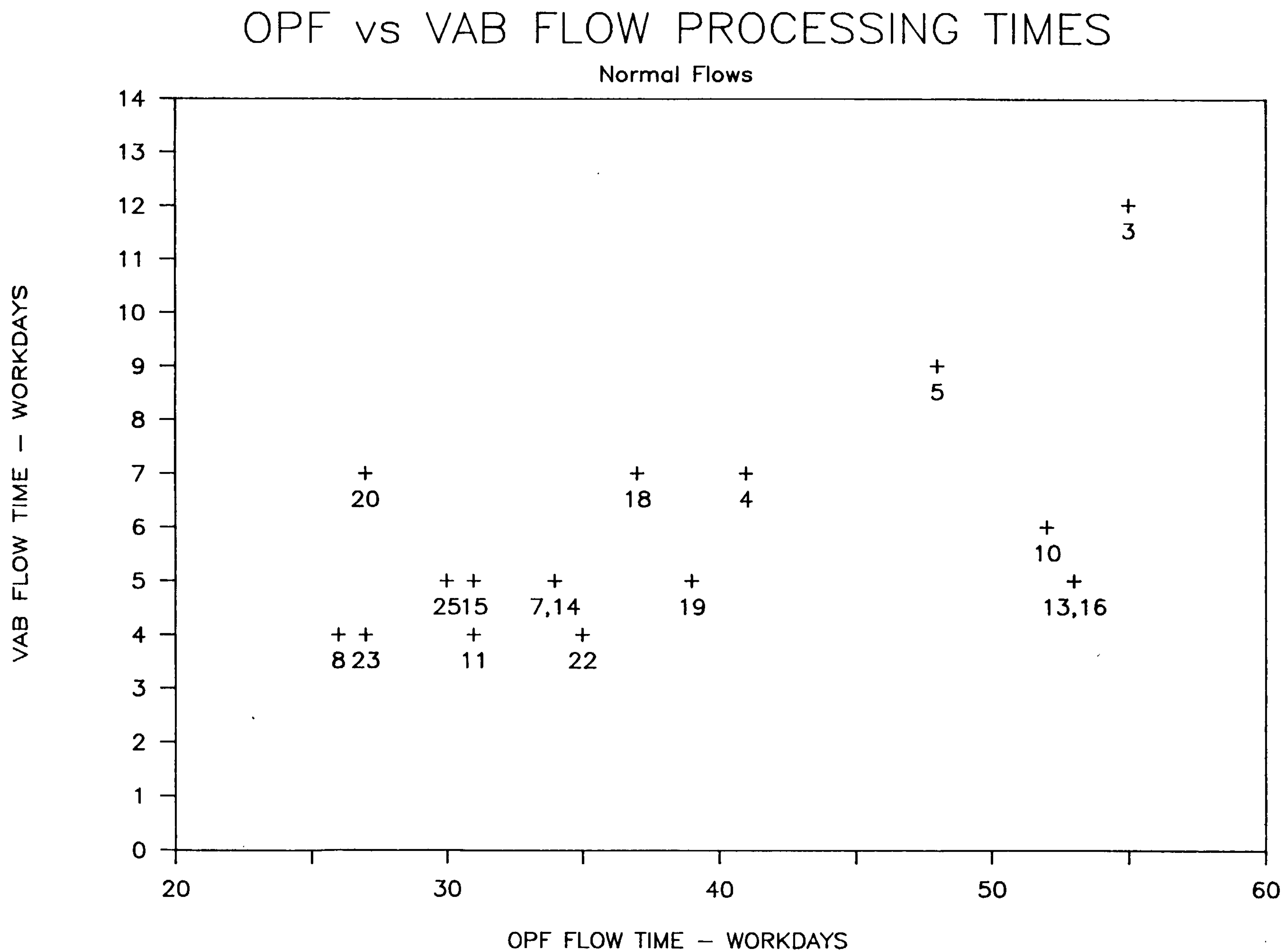
OPF vs VAB FLOW PROCESSING TIMES
Normal Flows
VAB FLOW TIME – WORKDAYS
OPF FLOW TIME – WORKDAYS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
20
30
40
50
60
20
8
23
25
15
11
7,14
22
18
19
4
5
10
13,16
3

Figure 2a

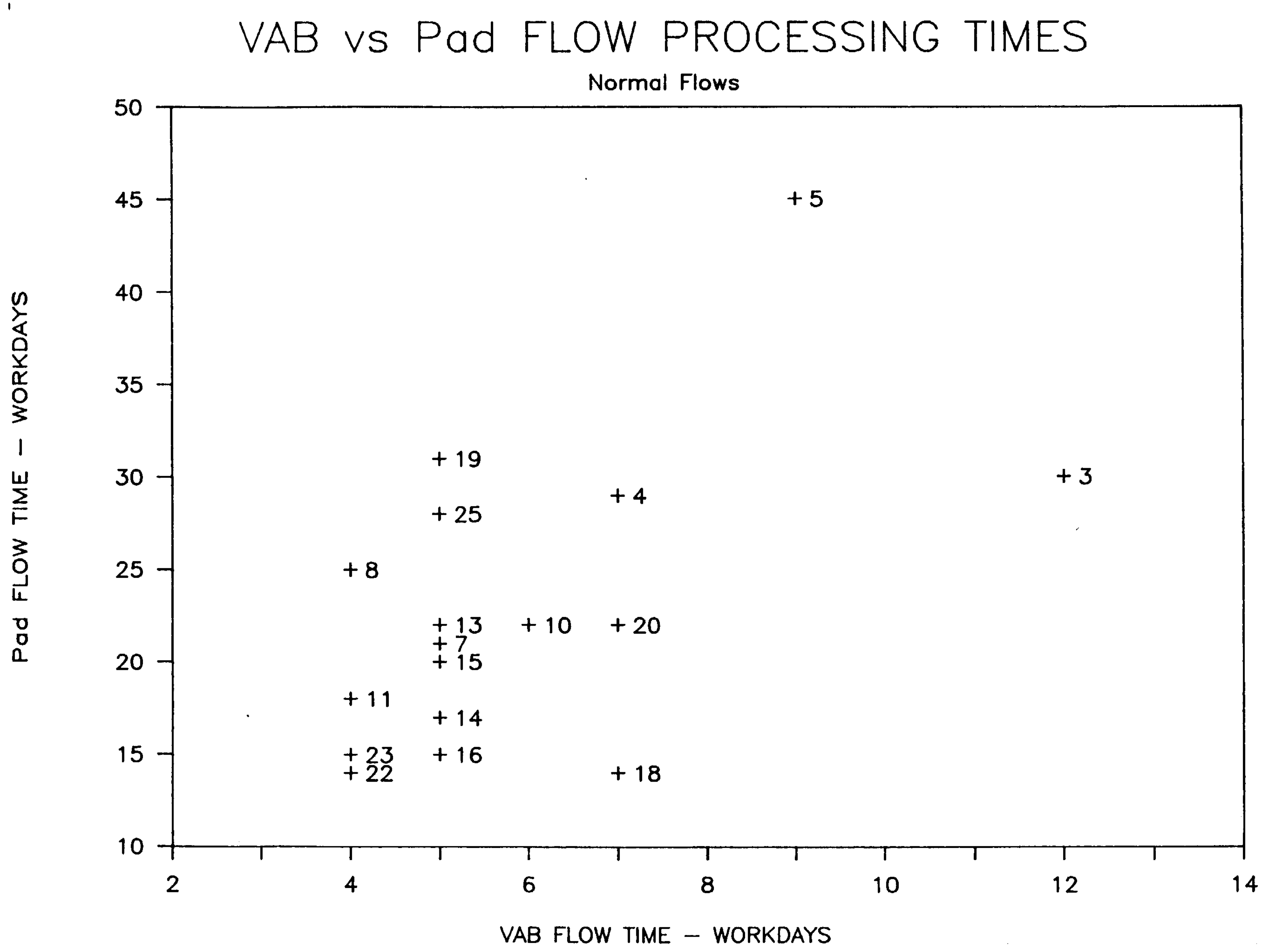
VAB vs Pad FLOW PROCESSING TIMES
Normal Flows
Pad FLOW TIME — WORKDAYS
VAB FLOW TIME — WORKDAYS
50
45
40
35
30
25
20
15
10
2
4
6
8
10
12
14
+ 5
+ 19
+ 3
+ 4
+ 25
+ 8
+ 13
+ 10
+ 20
+ 7
+ 15
+ 11
+ 14
+ 23
+ 16
+ 22
+ 18

Figure 2b

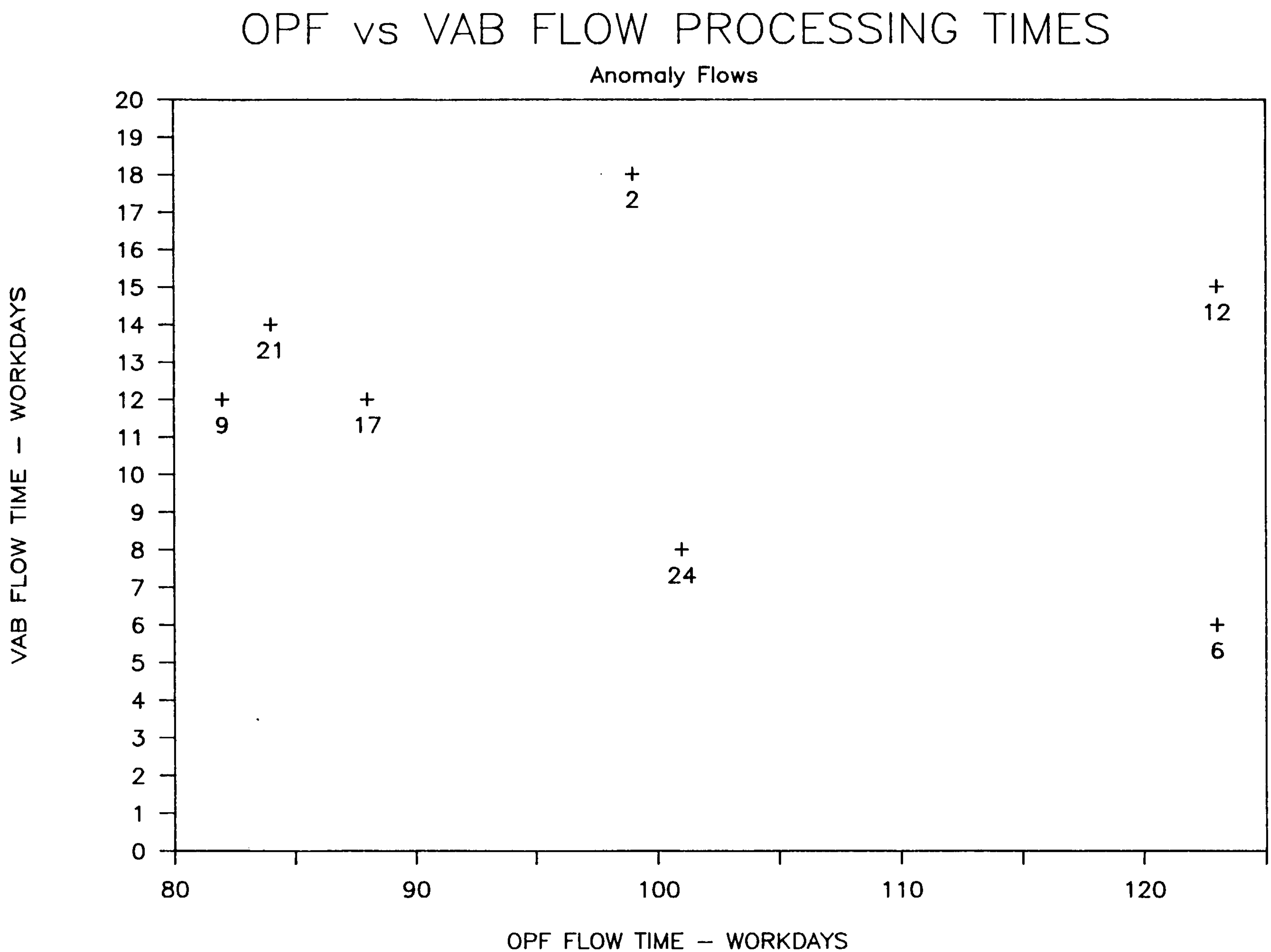
OPF vs VAB FLOW PROCESSING TIMES
Anomaly Flows
VAB FLOW TIME — WORKDAYS
OPF FLOW TIME — WORKDAYS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
80
90
100
110
120
9
21
17
2
24
12
6

Figure 3a

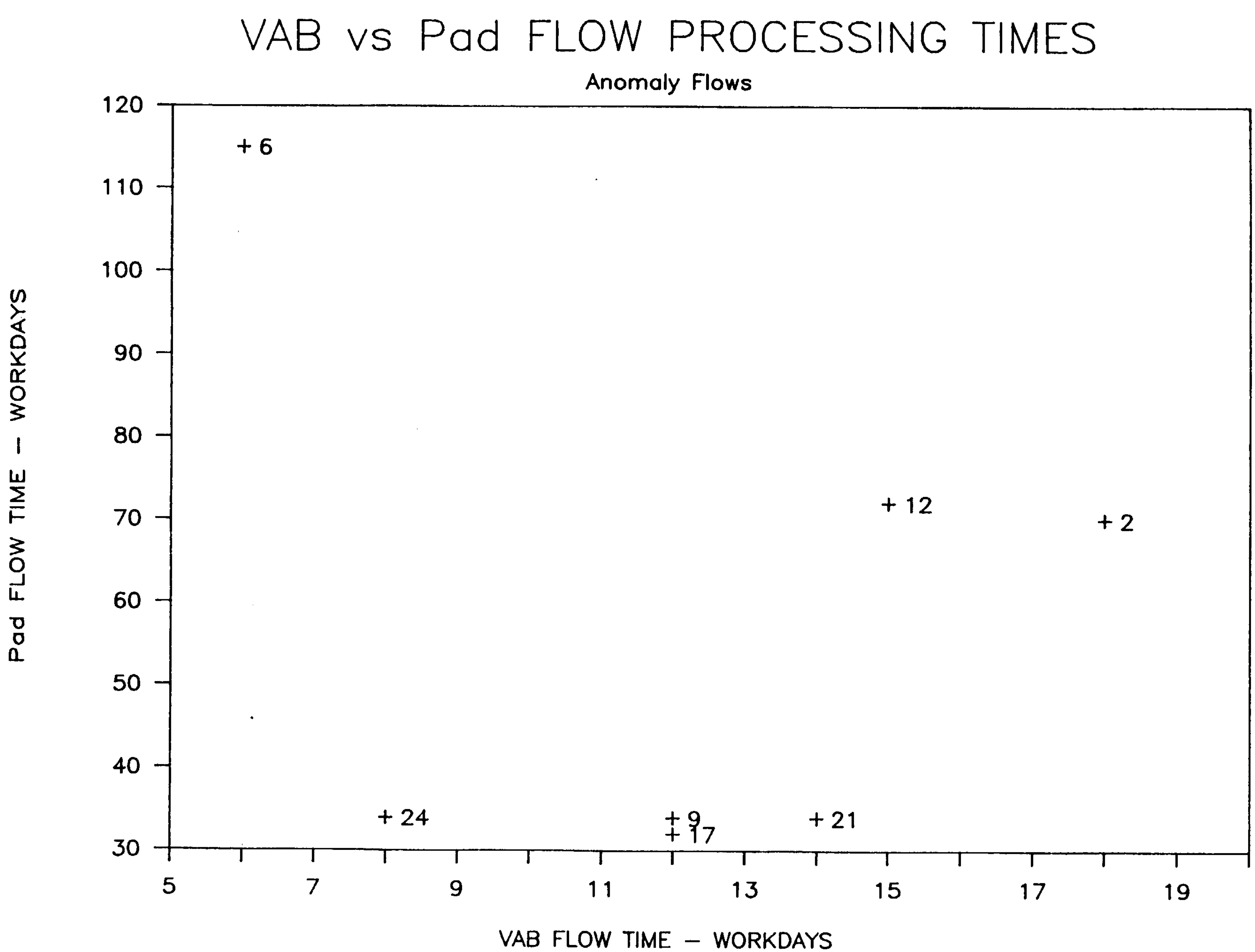
VAB vs Pad FLOW PROCESSING TIMES
Anomaly Flows
Pad FLOW TIME – WORKDAYS
VAB FLOW TIME – WORKDAYS
120
110
100
90
80
70
60
50
40
30
5
7
9
11
13
15
17
19
+ 6
+ 24
+ 9
+ 17
+ 21
+ 12
+ 2

Figure 3b

apparent. As shown in Figs. 3a and b considerably more data scatter is present for the Anomaly flow cases than for the Normal flow cases. If a causal relationship exists between the KSC facilities processing times for the Anomaly flows it is not visible to the naked eye.

To establish the validity of these observations, an assessment of the correlation factors between the facilities is accomplished in the manner outlined by Miller and Freund [5]. In this method, the sample correlation coefficient r is evaluated as:

$$r = S_{xy} / \sqrt{(S_{xx}\ S_{yy})},$$

where

$$S_{xx} = n \sum x_i^2 - (\sum x_i)^2$$

$$S_{yy} = n \sum y_i^2 - (\sum y_i)^2$$

$$S_{xy} = n \sum x_i y_i - (\sum x_i)\ (\sum y_i)$$

and n = the number of data points.

Having calculated r, the null hypothesis, H_o, that the actual correlation coefficient, $\rho=0$ may be tested at the desired level of significance, α, using the relation

$$z = Z \cdot \sqrt{(n-3)}$$

with the value of Z being obtained from an appropriate table or from the expression

$$Z = 1/2 \cdot \ln((1+r)/(1-r)).$$

The H_o must be rejected if z calculated as above is greater than $z_{\alpha/2}$ from a standard normal table.

The results of this analysis are given in Table 2 and show that for the Normal flows we must reject the H_o (with significance level $\alpha= 0.05$) that the correlation coefficient, $\rho=0$ for both OPF vs VAB and VAB vs Pad. Thus

Table 2a

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, $\rho=0$.

"Normal Flows"

Mission Seq No.	OPF x	VAB y	x^2	y^2	xy
3	55	12	3025	144	660
4	41	7	1681	49	287
5	48	9	2304	81	432
7	34	5	1156	25	170
8	26	4	676	16	104
10	52	6	2704	36	312
11	31	4	961	16	124
13	53	5	2809	25	265
14	34	5	1156	25	170
15	31	5	961	25	155
16	53	5	2809	25	265
18	37	7	1369	49	259
19	39	5	1521	25	195
20	27	7	729	49	189
22	35	4	1225	16	140
23	27	4	729	16	108
25	30	5	900	25	150
SUM=	653	99	26715	647	3985

n= 17

Sxx=	27746	r=	0.537
Syy=	1198	Z=	0.600
Sxy=	3098	z=	2.25

For confidence level $\alpha=0.05$, $z_{\alpha/2}=1.96$ (see Ref 8). Since z calculated above is greater than 1.96 we must reject the Ho that the correlation coefficient, $\rho=0$.

Table 2b

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, ρ=0.

"Normal Flows"

Mission Seq No.	VAB x	Pad y	x^2	y^2	xy
3	12	30	144	900	360
4	7	29	49	841	203
5	9	45	81	2025	405
7	5	21	25	441	105
8	4	25	16	625	100
10	6	22	36	484	132
11	4	18	16	324	72
13	5	22	25	484	110
14	5	17	25	289	85
15	5	20	25	400	100
16	5	15	25	225	75
18	7	14	49	196	98
19	5	31	25	961	155
20	7	22	49	484	154
22	4	14	16	196	56
23	4	15	16	225	60
25	5	28	25	784	140
SUM=	99	388	647	9884	2410

n= 17

Sxx=	1198	r=	0.559
Syy=	17484	Z=	0.631
Sxy=	2558	z=	2.36

For confidence level α=0.05, $z_{\alpha/2}$ =1.96 (see Ref 8). Since z calculated above is greater than 1.96 we must reject the Ho that the correlation coefficient, ρ=0.

Table 2c

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, ρ=0.

"Anomaly Flows"

Mission Seq No.	OPF x	VAB y	x^2	y^2	xy
2	99	18	9801	324	1782
6	123	6	15129	36	738
9	82	12	6724	144	984
12	123	15	15129	225	1845
17	88	12	7744	144	1056
21	84	14	7056	196	1176
24	101	8	10201	64	808
SUM=	700	85	71784	1133	8389

n= 7

Sxx=	12488	r=	-0.262
Syy=	706	Z=	-0.268
Sxy=	-777	z=	-0.54

For confidence level α=0.05, $z_{\alpha/2}$ =1.96 (see Ref 8). Since z calculated above is less than 1.96 we cannot reject the Ho that the correlation coefficient, ρ=0.

Table 2d

Test of Null Hypothesis, Ho.
Ho: correlation coefficient, ρ=0.

"Anomaly Flows"

Mission Seq No.	VAB x	Pad y	x^2	y^2	xy
2	18	70	324	4900	1260
6	6	115	36	13225	690
9	12	34	144	1156	408
12	15	72	225	5184	1080
17	12	32	144	1024	384
21	14	34	196	1156	476
24	8	34	64	1156	272
SUM=	85	391	1133	27801	4570

n= 7

Sxx= 706
Syy= 41726
Sxy= -1245

r= -0.229
Z= -0.234
z= -0.47

For confidence level α=0.05, $z_{\alpha/2}$ =1.96 (see Ref 8). Since z calculated above is less than 1.96 we cannot reject the Ho that the correlation coefficient, ρ=0.

we must conclude that the individual facility processing times have some significant relationship between them and cannot be simulated individually.

The individual facility processing times for the Anomalous flows appear to have no significant relationship since we were unable to reject the H_0, above. This allows us to simulate the facility flow times for the Anomaly cases individually if we desire. But we are already constrained to use the total flow for the Normal case and therefore will not profit by simulating the individual facilities for the Anomaly case.

II.B. Weibull Statistical Distribution Fitted to Facility Processing Times.

When the cumulative experience in the processing facilities at KSC is plotted in ascending order of time (workdays) required, the result is a cumulative histogram of the processing flow experience. The three-parameter Weibull distribution is fitted to this data to provide the desired means to determine processing time confidence intervals.

Kapur and Lamberson [6] give the cumulative form of the three-parameter Weibull distribution as:

$$F(x; \theta, \beta, \delta) = 1 - \exp-[(x-\delta)/(\theta-\delta)]^{\beta}, \quad x>=\delta$$

where $\beta>0$, $\theta>0$, and $\delta>=0$. The Weibull slope or shape parameter is β; the scale parameter or the characteristic life is θ; and the minimum life or location parameter is δ. For the purposes of this analysis the parameter δ

represents the minimum processing time associated with a particular facility or total flow time. To fit the Weibull distribution to the data, the shape and scale parameters and the minimum processing time are allowed to vary in value until a best fit of the data is obtained.

The quality of the Weibull curve fit for the total facility processing time histories (for both the normal and the anomalous flows) is measured by the Kolmogorov-Smirnov (KS) goodness of fit test. The Weibull distributions fit to these data are all evaluated at the 0.20 significance level (that is, we are willing to accept a 20% chance of discarding an acceptable fit). The results of the Weibull fits are summarized in Tables 3 and 4, along with the maximum KS statistic determined from each curve fit and the critical value corresponding to the KS significance level as given by Mann et al [7]. Figures 4 and 5 show the Weibull distributions fitted to the facility time history data.

II.C. Simulation of the KSC Shuttle Processing Flow.

Using the Weibull distributions previously fit to the Normal and Anomaly flow times, above, we now are able to simulate the processing of shuttle missions to experimentally establish the flight rate.

The expression for the cumulative Weibull distribution may be conveniently reorganized to generate flow processing times given the input of a uniformly distributed random variate. From before we have the cumulative Weibull:

Table 3

Weibull Curve Fits and Goodness-of-Fit Test
"Normal Flows"

WEIBULL PARAMETERS		#FLOWS	TIME	Fn	Weibull	Abs Diff
Theta	67.79		20	0.000	0.000	
Beta	1.20		45		0.000	
Delta	45	1	46	0.059	0.023	0.036
		2	53	0.176	0.248	0.071
#flights	17	1	55	0.235	0.311	0.075
		3	56	0.412	0.341	0.071
		1	58	0.471	0.399	0.071
		1	60	0.529	0.454	0.075
		1	63	0.588	0.529	0.059
			64		0.552	
			66		0.596	
			68		0.636	
			71		0.690	
			72		0.706	
		1	73	0.647	0.722	0.075
		1	75	0.706	0.751	0.045
		1	77	0.765	0.777	0.013
			78		0.790	
			79		0.801	
		2	80	0.882	0.812	0.070
			82		0.833	
			84		0.851	
			86		0.868	
			89		0.889	
			90		0.896	
			92		0.908	
			94		0.918	
			96		0.928	
		1	97	0.941	0.932	0.009
			98		0.936	
			100		0.944	
		1	102	1.000	0.950	0.050
			104		0.956	
			106		0.962	
			108		0.966	
			110		0.970	
			112		0.974	
			114		0.977	
			116		0.980	
			118		0.982	
			120		0.985	
		17			MAXDIFF=	0.075

For Alpha=0.2 and n=17, the Kolmogorov-Smirnov critical value =0.169 (see Ref 7). Because the MAXDIFF is less than the critical value we cannot reject the Ho that the sample came from a Weibull distribution with parameters given above.

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Table 4

Weibull Curve Fits and Goodness-of-Fit Test
"Anomaly Flows"

WEIBULL PARAMETERS		#FLOWS	TIME	Fn	Weibull	Abs Diff
Theta	159.52		105		0.000	
Beta	1.20		110		0.000	
Delta	110		115		0.062	
			120		0.136	
#flights	7		125		0.212	
		1	128	0.143	0.257	0.114
		2	132	0.429	0.315	0.114
			140		0.422	
		1	143	0.572	0.459	0.113
			150		0.539	
			155		0.590	
			160		0.636	
			165		0.678	
			170		0.716	
			175		0.750	
			180		0.780	
		1	187	0.714	0.817	0.103
			190		0.831	
			195		0.852	
			200		0.871	
			205		0.888	
		1	210	0.857	0.902	0.045
			215		0.915	
			220		0.926	
			225		0.936	
			230		0.945	
			235		0.952	
			240		0.959	
		1	244	1.000	0.963	0.037
			250		0.969	
			255		0.973	
			260		0.977	
			265		0.980	
			270		0.983	
			275		0.986	
			280		0.988	
			285		0.989	
			290		0.991	
			295		0.992	
			300		0.993	
		7			MAXDIFF=	0.114

For Alpha=0.2 and n=7, the Kolmogorov-Smirnov critical value =0.247 (see Ref 7). Because the MAXDIFF is less than the critical value we cannot reject the Ho that the sample came from a Weibull distribution with parameters given above.

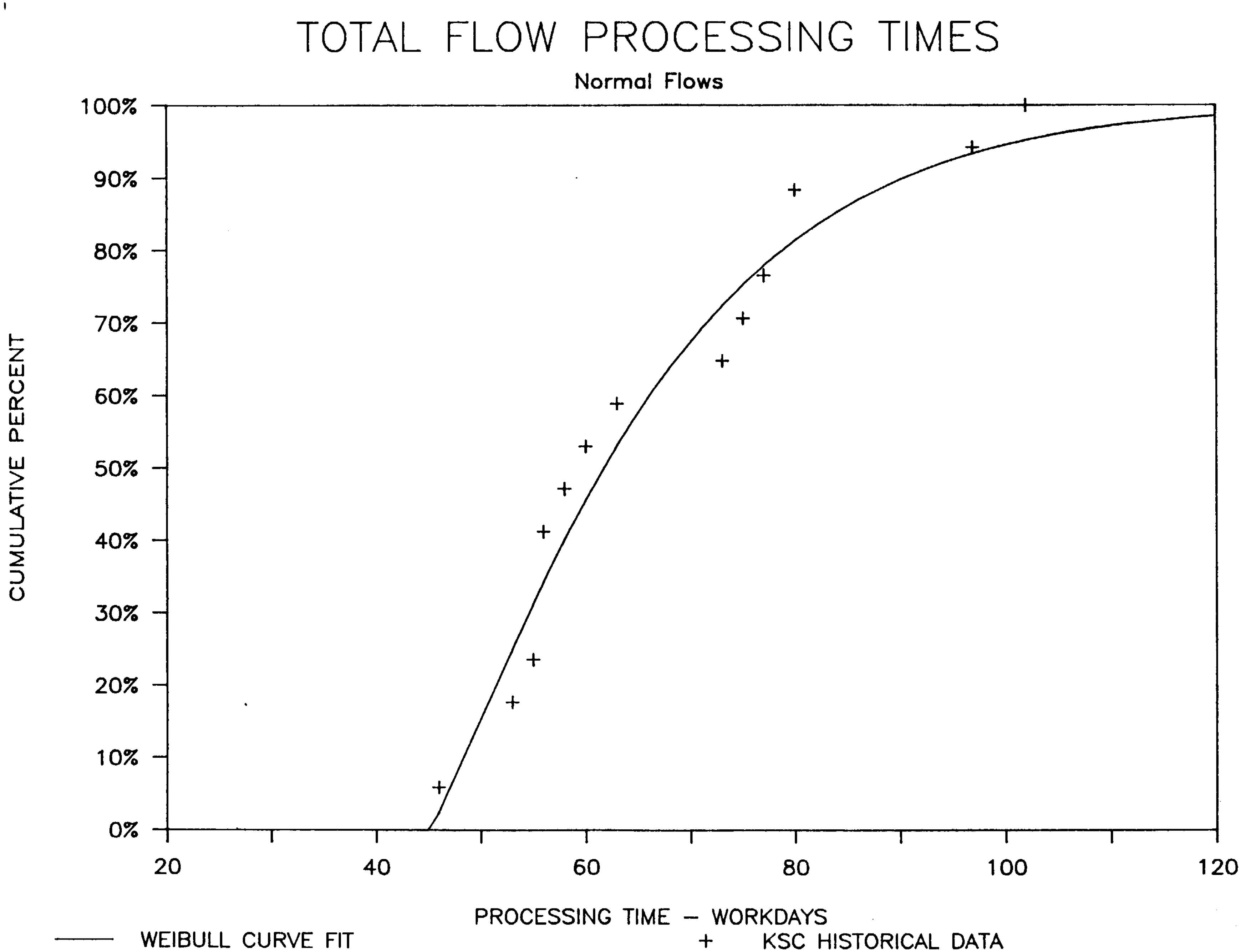
TOTAL FLOW PROCESSING TIMES
Normal Flows
CUMULATIVE PERCENT
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
20
40
60
80
100
120
PROCESSING TIME – WORKDAYS
WEIBULL CURVE FIT
+ KSC HISTORICAL DATA

Figure 4

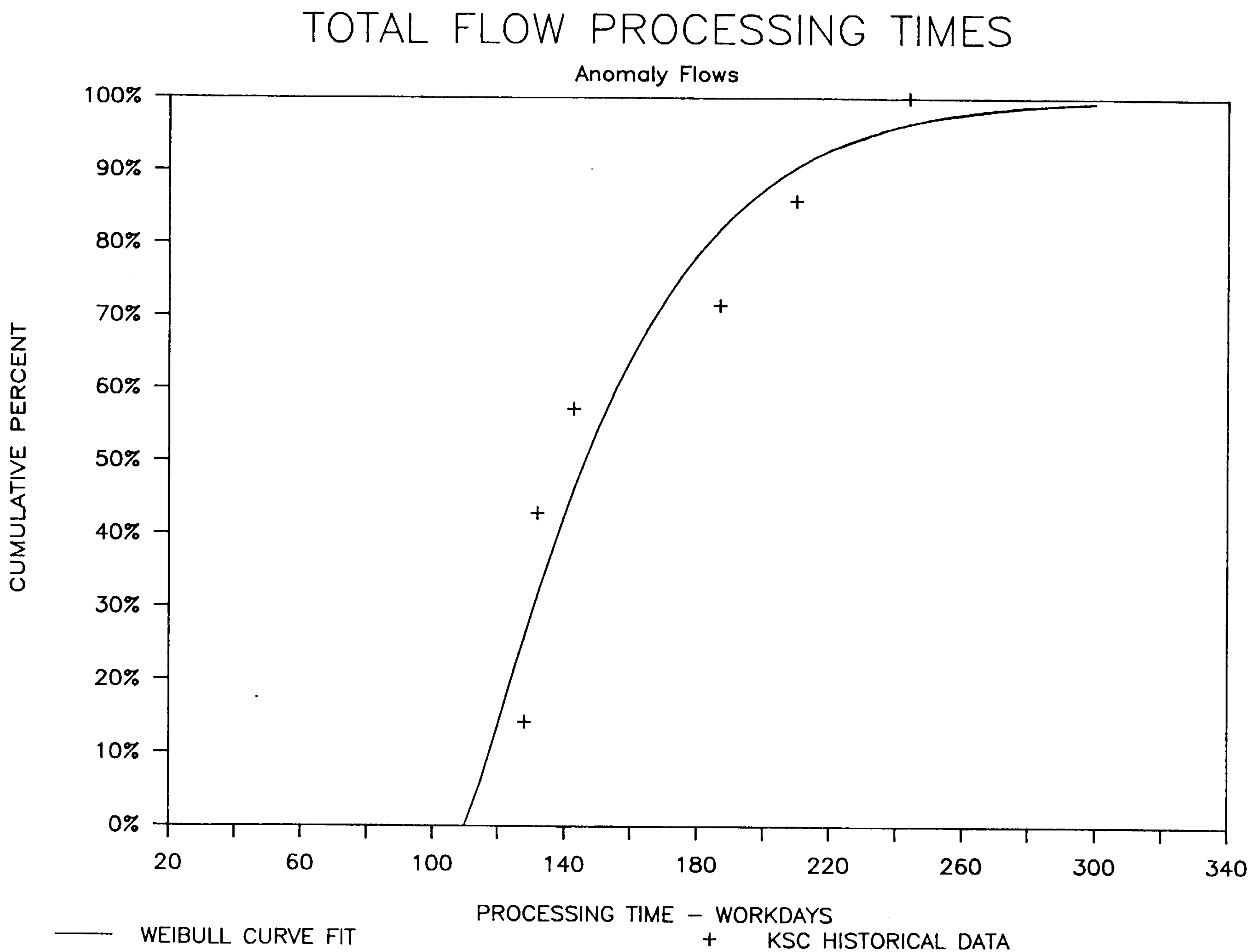
TOTAL FLOW PROCESSING TIMES
Anomaly Flows
CUMULATIVE PERCENT
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
20
60
100
140
180
220
260
300
340
PROCESSING TIME – WORKDAYS
WEIBULL CURVE FIT
+ KSC HISTORICAL DATA

Figure 5

$$F(x;\ \theta,\ \beta,\ \delta) = 1 - \exp-[(x-\delta)/(\theta-\delta)]^{\beta}\ , \quad x>=\delta.$$

Now let $F(x;\ \theta,\ \beta,\ \delta) = U$, a uniformly distributed random variate. Substituting and solving for x we obtain:

$$x = [(\theta - \delta)(\ln(1 - U))^{1/\beta}] + \delta.$$

The parameters θ, β, and δ are known from before and the random variate U is input to generate x, a processing time along the Weibull distribution described by θ, β, and δ. The approach taken to simulate the Shuttle processing flow is as follows:

Using the previously derived parameters for the Weibull distributions, 50 Normal and 50 Anomaly shuttle processing flows are randomly generated. One set of such randomly generated flows is shown in Table 5. In order to calculate a total processing time to produce 50 shuttle processing flows, these flows must be summed with attention given to the expected proportion of Normal vs Anomaly flows.

As stated in Assumption 3, we may expect one-fourth of the future flights to be Anomalies. Thus, the sum of the 50 generated processing times is taken to be 3/4 of the sum of the 50 Normal flows plus 1/4 of the sum of the 50 Anomaly flows (again, see Table 5).

The above is repeated 50 times to generate a total of 50 sets of 50 processing flows. The number of flows and sets of flows was chose to be 50 for two reasons. First, if fewer than 30 sets of flows are used, the confidence intervals of the resulting distribution for the mean processing time must be calculated using the Students-t

Table 5
Simulation of Shuttle Processing Flows
Using Weibull Distributions

Simulation of Fifty Normal Flows

WEIBULL PARAMETERS

theta=	67.79
beta=	1.2
delta=	45

1	47.8
2	70.5
3	58.1
4	57.4
5	76.9
6	55.1
7	59.2
8	94.4
9	79.6
10	100.3
11	51.5
12	56.1
13	49.5
14	76.5
15	74.2
16	60.8
17	63.7
18	76.1
19	60.8
20	56.6
21	46.1
22	52.7
23	82.7
24	87.9
25	50.6
26	106.8
27	122.3
28	91.2
29	69.7
30	84.0
31	64.1
32	119.6
33	82.6
34	51.9
35	61.4
36	69.5
37	53.2
38	64.2
39	97.1
40	54.7
41	58.1
42	112.1
43	50.8
44	61.0
45	58.5
46	47.4
47	70.1
48	112.9
49	85.4
50	59.5
sum=	3553.3

Simulation of Fifty Anomaly Flows

WEIBULL PARAMETERS

theta=	159.52
beta=	1.2
delta=	110

1	128.0
2	115.3
3	176.0
4	115.4
5	151.9
6	158.1
7	111.5
8	119.1
9	187.1
10	133.8
11	140.0
12	161.7
13	135.5
14	162.9
15	120.0
16	212.0
17	153.6
18	174.2
19	203.3
20	167.8
21	173.9
22	190.5
23	124.4
24	213.4
25	125.3
26	141.1
27	113.1
28	189.8
29	204.7
30	132.2
31	153.9
32	131.1
33	255.8
34	130.8
35	146.6
36	165.8
37	119.2
38	199.8
39	141.4
40	158.3
41	188.6
42	159.4
43	186.7
44	158.4
45	119.1
46	147.7
47	251.3
48	143.7
49	163.9
50	193.8
sum=	7950.9

One Set of Fifty Processing Flows

three quarters normal	2665.0
one quarter anomaly	1987.7
SUM	4652.7

distribution. This would yield a confidence interval unacceptably large for this application. Using more than 30 samples (flows) allows the use of the Standard Normal distribution to calculate confidence intervals. As desired, the confidence interval width decreases as the number of samples (flows) increases.

However, these simulations were accomplished on a microcomputer using the LOTUS 1-2-3 spreadsheet and graphics programs. The simulation rapidly gets too unwieldy and demanding of computer time if a very large number of samples is used. Because 50 flows and sets of flows yields a satisfactory confidence interval width (as will be shown below) the author settled upon this number as a matter of practicality. The 50 sets of 50 randomly generated processing flows are shown in Table 6.

II.D. Determination of Confidence Intervals for Mean Processing Flow Time.

By the Central Limit Theorem, the mean processing times for the 50 sets of flows are taken to be normally distributed. Thus, confidence intervals for the true mean, μ, of the time to process 50 flights may be calculated. The method used is that shown by Walpole and Meyers [8] for the case where the distribution's standard deviation, σ, is unknown, but the sample standard deviation, s, may be used as an approximation. The confidence interval is calculated by:

$$\bar{x} - Z_{\alpha/2}(s/\sqrt{n}) < \mu < \bar{x} + Z_{\alpha/2}(s/\sqrt{n})$$

Table 6

Fifty Sets of Fifty Flows

Normal distribution		Z(alpha/2)	
Mean	4439.9	99%	2.575
Variance	10814.5	95%	1.960
SDev	104.0	90%	1.645

Confidence Intervals for Mean
Time to Process 50 Flights

99%	4402.1	<=Xbar<=	4477.8	workdays
95%	4411.1	<=Xbar<=	4468.8	
90%	4415.7	<=Xbar<=	4464.1	

Fifty Sets of
Fifty Processing Flows

	X	X^2
1	4219.6	17805203
2	4252.1	18080629
3	4278.5	18305635
4	4299.1	18482601
5	4299.4	18485039
6	4314.5	18615208
7	4318.3	18647698
8	4319.5	18658109
9	4320.9	18669874
10	4341.9	18851996
11	4354.3	18959615
12	4362.0	19027092
13	4364.3	19047363
14	4371.6	19110746
15	4389.1	19264094
16	4391.5	19285102
17	4391.5	19285367
18	4392.1	19290140
19	4394.2	19308795
20	4422.9	19561763
21	4423.8	19569800
22	4426.4	19593218
23	4431.0	19633736
24	4433.2	19652961
25	4434.8	19667821
26	4438.6	19700742
27	4438.9	19703562
28	4440.1	19714164
29	4447.0	19775644
30	4449.5	19797756
31	4472.6	20004276
32	4472.7	20004892
33	4479.6	20066533
34	4483.3	20100255
35	4488.5	20146757
36	4489.5	20155943
37	4497.3	20225434
38	4507.0	20312947
39	4517.5	20408068
40	4530.1	20521591
41	4532.1	20539789
42	4534.6	20562401
43	4561.5	20807144
44	4578.8	20965189
45	4580.3	20979330
46	4580.4	20979714
47	4595.3	21116354
48	4617.0	21316660
49	4643.6	21563284
50	4674.3	21849063
SUM	221996.3	9.9E+08

where $(1 - \alpha)100\%$ is the desired confidence level, $Z_{\alpha/2}$ is the value of the standard normal distribution with an area of $\alpha/2$ to the right, $\bar{x}$ is the mean of our size n sample, and the sample standard deviation

$$s = \sqrt{[(\sum x^2 - n(\sum x)^2) \ / \ (n(n-1))]}.$$

The results of these calculations are given in Table 6 for levels of confidence of 90, 95, and 99 percent. Having calculated the confidence interval for the mean time to process 50 flights, μ, this data may be used to calculate the confidence interval for the NSTS flight rate.

II.E. Results of Flight Rate Calculations Using Statistical Distributions.

Thus far we have only accounted for the time to process the space shuttle hardware processing time. We must also allow for time of flight and transportation time for the orbiter after landing. An additional allowance of time is added to the above flow processing time confidence interval limits to account for 50 seven day flights, and 25 five day returns from an Edwards Air Force Base landing (NASA's program plan calls for half of the future shuttle flights to land at Edwards AFB and the other half at KSC). The flight rate (FR) is now calculated by:

FR = #orbiters x #workdays/yr x 50 flights/#days required.

The results of these calculations are given in Table 7 for a four orbiter fleet, at confidence levels of 90, 95, and 99 percent, and for various numbers of workdays per week. As shown in Table 7, the NSTS flight rate estimates

Table 7

Calculation of NSTS Flight Rate from Table 6 Data

Additional Time Required for Flight
and Shuttle Orbiter Transportation

Flight Duration (7*50)	350
Transport to KSC (5*25)	125
Flight and Transport Time	475 workdays

4 Orbiter Fleet Mean Flight Rate

workdays/yr		
365	14.97 >=FRate>= 14.74	99% confidence
312	12.79 >=FRate>= 12.60	
260	10.66 >=FRate>= 10.50	
250	10.25 >=FRate>= 10.10	

workdays/yr		
365	14.94 >=FRate>= 14.77	95% confidence
312	12.77 >=FRate>= 12.62	
260	10.64 >=FRate>= 10.52	
250	10.23 >=FRate>= 10.11	

workdays/yr		
365	14.93 >=FRate>= 14.78	90% confidence
312	12.76 >=FRate>= 12.63	
260	10.63 >=FRate>= 10.53	
250	10.22 >=FRate>= 10.12	

range from approximately 10 flights per year to approximately 15 flights per year, depending on the number of workdays in a year.

III. Data Analysis Using Learning Curves

III.A Evaluation of Processing Time Learning Curves.

When displayed graphically in chronological order, the data for the Total Flow (the sum of the OPF, VAB, and Pad facility flow times) appear to display a trend toward decreased processing time as flight experience increases. This gives rise to the supposition that the flow processing times are not a purely random process. To test this a learning curve is fit to the KSC facility data.

The learning curve expression is given by Chase and Aquilano [9] as:

$$Y_x = K \cdot X^b, \quad \text{where } b = \mathrm{Log}_{10}(R)/\mathrm{Log}_{10}(2)$$

R = the learning rate $0<R<=1$

K = processing time for the first Flow

Y_x = processing time for the x'th Flow

This expression is fitted to the Total Flow data using the Kolmogorov-Smirnov goodness of fit test discussed in section II.B. This is done for both the Normal and Anomaly flows.

Fitting a single learning curve to all of the normal flows yields unsatisfactory results due to the dispersion present in the data. Application of control limits to the learning curve gives no improvement. For example: more than five percent of the cumulative experience falls outside of the calculated 95% control limits (Fig 6).

Better results may be had by bounding the data with optimistic and pessimistic learning curves. The optimistic

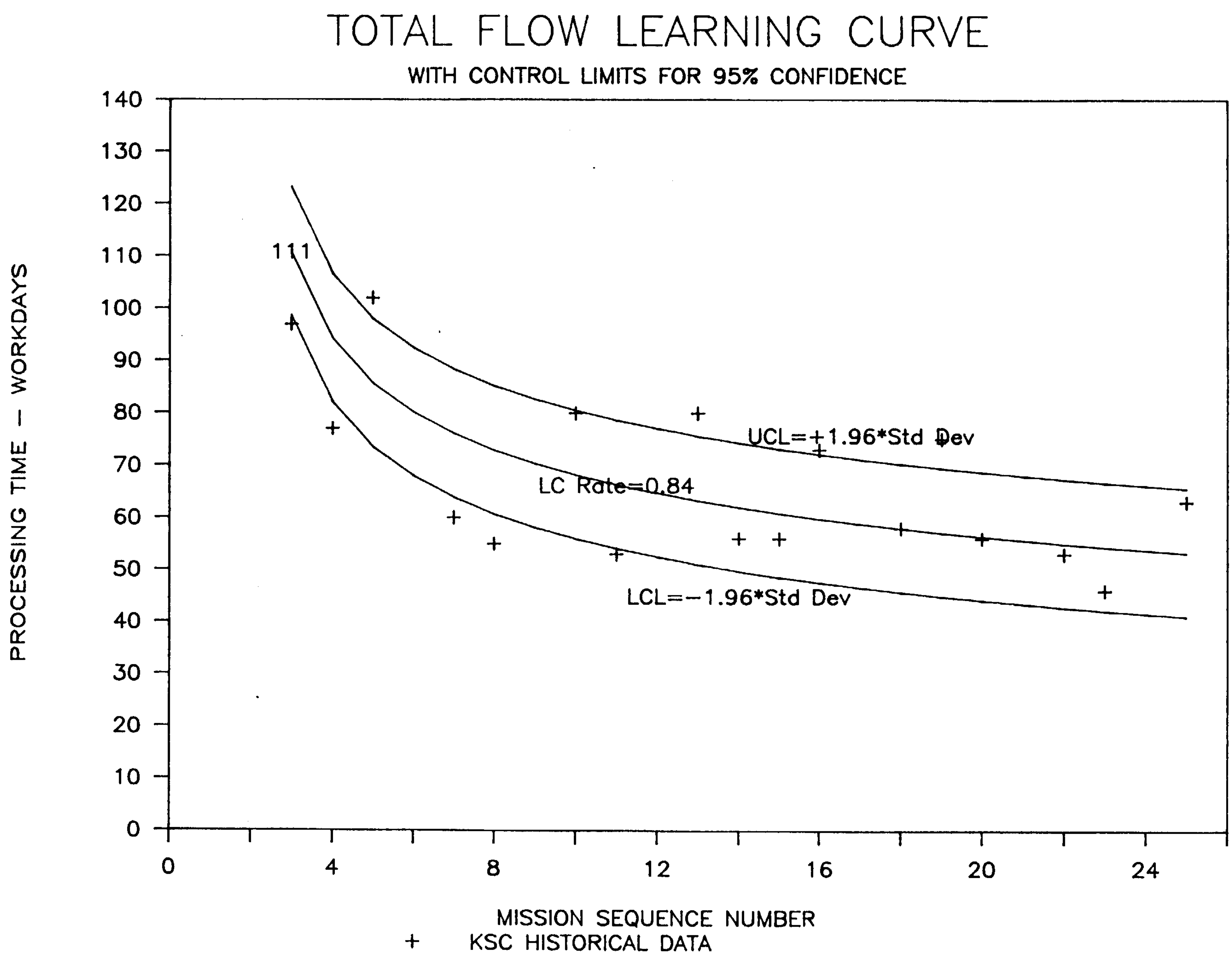
TOTAL FLOW LEARNING CURVE
WITH CONTROL LIMITS FOR 95% CONFIDENCE
PROCESSING TIME — WORKDAYS
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
111
UCL=+1.96*Std Dev
LC Rate=0.84
LCL=−1.96*Std Dev
0
4
8
12
16
20
24
MISSION SEQUENCE NUMBER
+ KSC HISTORICAL DATA

Figure 6

learning curve is the best fitting learning curve calculated for the outlying data on the low extreme of the experience time range. The pessimistic learning curve is the best fitting learning curve calculated for the outlying data on the high extreme of the experience time range.

The Anomaly flow learning curves use flight number two as an initial point. The Normal flow learning curves use flight number three as an initial point (flight number three is the first flight considered "normal"). Processing time for the initial points is allowed to be variable to achieve a best fit of the learning curves to the data. Tables 8 and 9 summarize the results of the successful learning curve fits to bound the flow processing time experience ranges with optimistic and pessimistic learning curves. Those tables also indicate the data points used to fit the optimistic and pessimistic learning curves. Figures 7 and 8 show these results graphically for the Normal and Anomaly flows, respectively.

III.B Estimation of Flow Processing Times for Future Flights Using Learning Curve Results.

The learning curves determined above are used to estimate the NSTS flight rate in much the same manner as the Weibull distributions in section II.C. But, since the processing times estimated by the learning curves are a function of both the learning rate and the flow number, and are not randomly generated, a slightly different technique must be used.

Table 8

TOTAL FLOW LEARNING CURVE
"Normal Flows"

Mission Seq #	LrnCurve Seq #	Total Flow Time	OPTIMISTIC LEARNING CURVE Data Pt Used	Rate 0.83	Abs Diff Tot-Calc	PESSIMISTIC LEARNING CURV Data Pt Used	Rate 0.88	Abs Diff Tot-Calc
1								
2								
3	1	97	*	95	2.000		120	
4	2	77	*	79	1.850		106	
5	3	102		71		*	98	4.009
6	4			65			93	
7	5	60	*	62	1.635		89	
8	6	55	*	59	3.687		86	
9	7			56			84	
10	8	80		54		*	82	1.777
11	9	53	*	53	0.373		80	
12	10			51			78	
13	11	80		50		*	77	2.888
14	12	56		49			76	
15	13	56		48			75	
16	14	73		47		*	74	0.758
17	15			46			73	
18	16	58		45			72	
19	17	75		44		*	71	3.837
20	18	56		44			70	
21	19			43			70	
22	20	53		42			69	
23	21	46	*	42	4.093		68	
24	22			41			68	
25	23	63		41		*	67	4.305
26	24			40			67	
28	26			40			66	
30	28			39			65	
32	30			38			64	
34	32			37			63	
36	34			37			63	
38	36			36			62	
40	38			36			61	

	Optimistic	Pessimistic
Max Absolute Difference	4.093	4.305
A: Max abs diff normalized by calculated flow time for Learning Curve Sequence #1.	0.043	0.036

Table 8, concluded.

Kolmogorov-Smirnov Goodness-of-Fit Test: Ho; the sample comes from a process whose learning curve is described by the rate and initial processing time described above.

B: Max Acceptable Absolute Difference for n=6, and Significance Level = 0.20.	0.265	0.265

Since A < B, for both the Optimistic and Pessimistic Learning Curves, we cannot reject the Ho for either case.

Table 9

TOTAL FLOW LEARNING CURVE
"Anomaly Flows"

Mission Seq #	LrnCurve Seq #	Total Flow Time	Optimistic Learning Curve Data Pt Used	Optimistic Rate 0.92	Optimistic Abs Diff Tot-Calc	Pessimistic Learning Curve Data Pt Used	Pessimistic Rate 0.95	Pessimistic Abs Diff Tot-Calc
1								
2	1	187	*	177	10.000		263	
3	2			163			250	
4	3			155			242	
5	4			150			237	
6	5	244		146		*	233	10.530
7	6			143			230	
8	7			140			228	
9	8	128	*	138	9.828		225	
10	9			136			224	
11	10			134			222	
12	11	210		133		*	220	10.238
13	12			131			219	
14	13			130			218	
15	14			129			216	
16	15			128			215	
17	16	132	*	127	5.198		214	
18	17			126			213	
19	18			125			212	
20	19			124			212	
21	20	132	*	123	8.557		211	
22	21			123			210	
23	22			122			209	
24	23	143		121			209	
25	24			121			208	
26	25			120			207	
28	27			119			206	
30	29			118			205	
32	31			117			204	
34	33			116			203	
36	35			115			202	
38	37			115			201	
40	39			114			201	

	Optimistic	Pessimistic
Max Absolute Difference	10.000	10.530
A: Max abs diff normalized by calculated flow time for Learning Curve Sequence #1.	0.056	0.040

Table 9, concluded

Kolmogorov-Smirnov Goodness-of-Fit Test: Ho; the sample comes from a process whose learning curve is described by the rate and initial processing time described above.

B: Max Acceptable Absolute Difference for n=4, and Significance Level = 0.20.	0.300	for n=2, and Significance Level = 0.20.	>0.300

Since A < B, for both the Optimistic and Pessimistic Learning Curves, we cannot reject the Ho for either case.

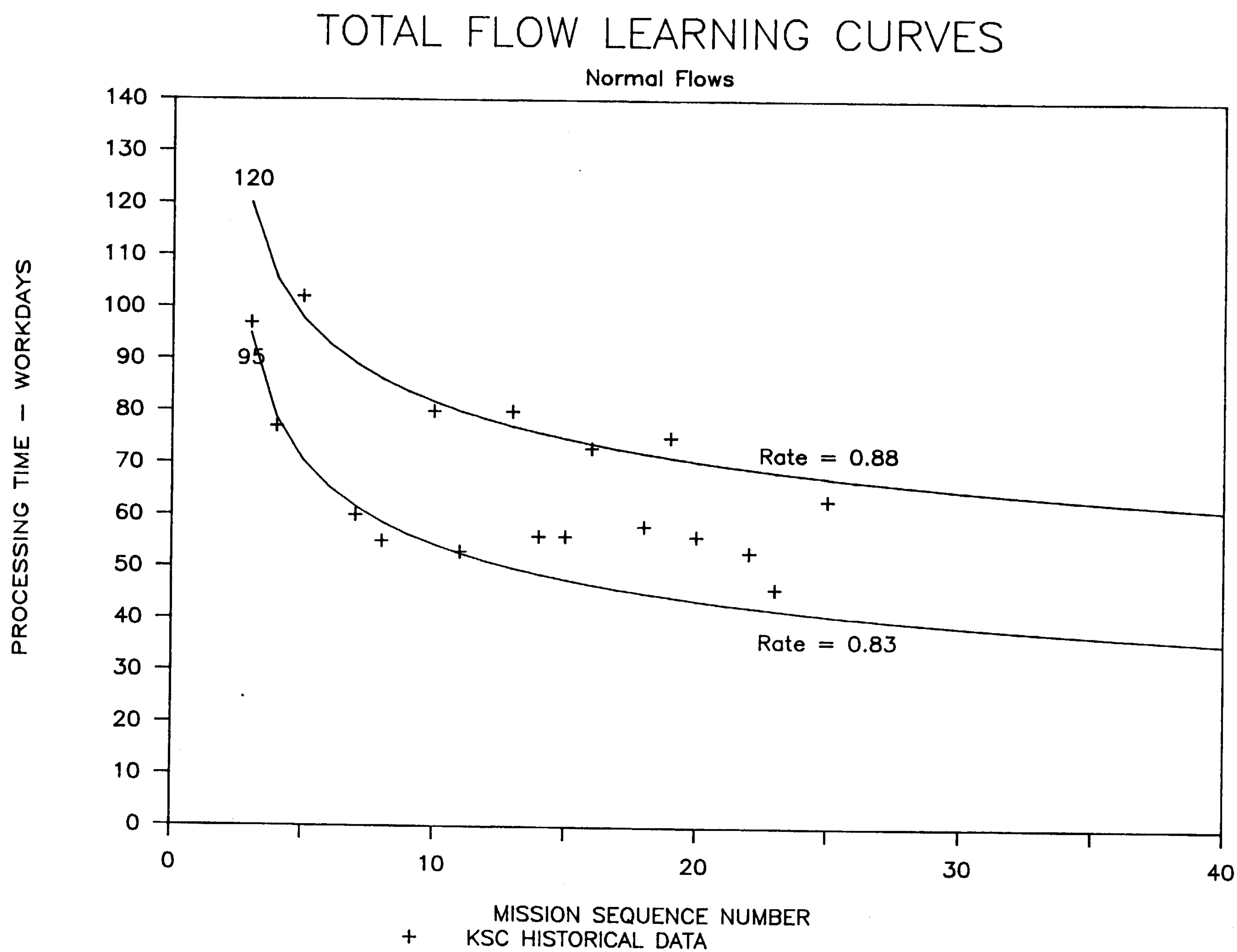
TOTAL FLOW LEARNING CURVES
Normal Flows
PROCESSING TIME - WORKDAYS
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
120
95
Rate = 0.88
Rate = 0.83
0
10
20
30
40
MISSION SEQUENCE NUMBER
+ KSC HISTORICAL DATA

Figure 7

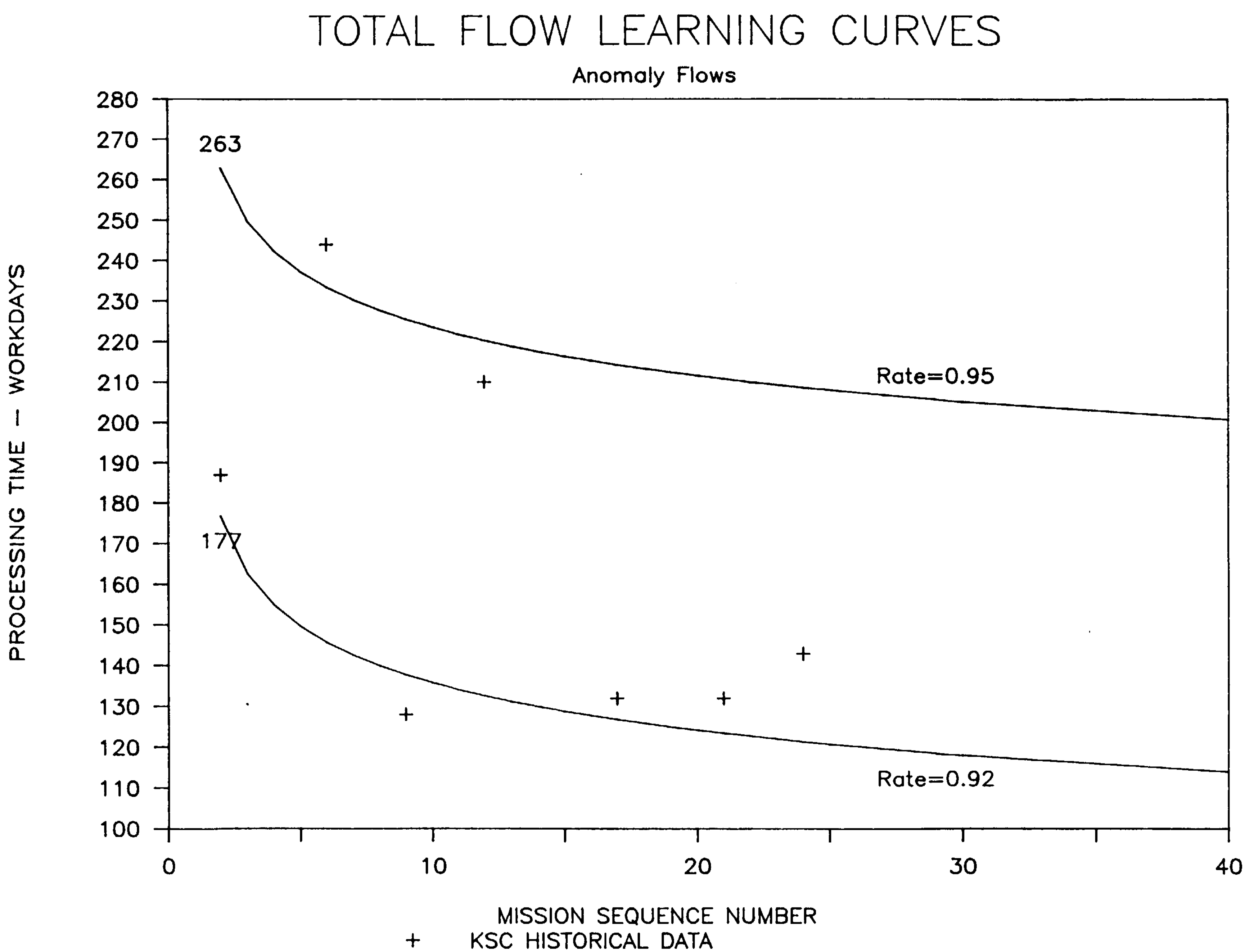
TOTAL FLOW LEARNING CURVES
Anomaly Flows
PROCESSING TIME – WORKDAYS
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
263
177
Rate=0.95
Rate=0.92
0
10
20
30
40
MISSION SEQUENCE NUMBER
+ KSC HISTORICAL DATA

Figure 8

For the analysis hypothetical flights 41 through 60 have been examined. These particular missions are of interest because, had the Challenger accident on mission sequence number 25 not occurred, the flight schedule would likely be in this range at the present time. Also, flights 41-60 are sufficiently far along on the learning curves that the change in processing time with increasing flight number approximates a straight line. Thus 20 flows are sufficient to determine the mean flight rate and we need not bother simulating 50 slows as in Section II.

Twenty processing flow times were generated for both the Normal and Anomaly flows, and are given in Table 10. As for the case described in section II.C, the sum of the 20 flow times is taken to be 3/4 of the sum of the 20 normal flow times plus 1/4 of the sum of the 20 anomaly flow times. To this was added 7 x 20 flight days and 5 x 10 orbiter transportation days to return from Edwards AFB (again, half the Shuttle landings are expected to occur at Edwards AFB, requiring 5 days transportation time to KSC).

III.C. Results of Learning Curve Flight Rate Calculations.

The average flight rate (FR) is calculated by:
FR = #orbiters x #workdays/yr x 20 flights/#days required.
Rather than calculate confidence intervals as was done previously, we are only able to provide optimistic and pessimistic flight rates. The results of the optimistic and pessimistic learning curve flight rate calculations are shown in Table 10. As shown, the mean flight rate for the

hypothetical flights 41-60 varies from an optimistic 22.7 at 365 workdays per year to a pessimistic 9.7 flights per year at 250 workdays per year.

Table 10

Calculation of NSTS Flight Rate
Using Results of Learning Curve Analysis

Mission Seq #	Generated Flow Times: Optimistic Normal	Optimistic Anomaly	Pessimistic Normal	Pessimistic Anomaly
41	35	114	61	200
42	35	113	61	200
43	35	113	60	199
44	35	113	60	199
45	35	112	60	199
46	34	112	60	198
47	34	112	59	198
48	34	111	59	198
49	34	111	59	197
50	34	111	59	197
51	33	111	59	197
52	33	110	58	197
53	33	110	58	196
54	33	110	58	196
55	33	110	58	196
56	33	109	58	196
57	32	109	57	195
58	32	109	57	195
59	32	109	57	195
60	32	108	57	194
SUM OF FLOW TIMES	671	2216	1175	3943
x	0.75	0.25	0.75	0.25
	503	554	881	986

	Optimistic	Pessimistic
Normal Flows	503	881
Anomaly Flows	554	986
Flight Duration (7x20)	140	140
Orb transport to KSC (5x10)	50	50
Total Workdays Required	1247	2057

4 Orbiter Fleet Flight Rate for various work weeks

Work days/week	Days/Yr	Flight Rate: Optimistic	Pessimistic
7 days/week	365	23.4	14.2
6 days/week	312	20.0	12.1
5 days/week	260	16.7	10.1
5/week - 10 holidays	250	16.0	9.7

IV. Conclusions

Conclusion 1: Because the results of the analyses in sections II and III are significantly different, the methods of analysis appear to be sensitive to the circumstances of their application. The flight rate analysis using probability distributions does not account for any Learning Curve effects. For an application such as the Space Shuttle processing flows, where the execution times can be quite large at first, Learning Curve effects may produce a significant change in system capacity over the long term. As shown in Section III, some Learning Curve effects are present in the past Shuttle processing experience data. Therefore, we must conclude that the application of a probabilistic flight rate analysis in these circumstances may yield pessimistic results compared to the actual future capacity of the system.

Conclusion 2: Based on the Caveats in section I.D and the results presented in Sections II and III, above, it appears likely that the NSTS program will experience difficulty in achieving the currently planned maximum sustained flight rate of 14 flights per year. Even though the results presented in section III show a flight rate capacity of up to about 23 flights per year, this was based upon a maximum effort work schedule requiring 365 workdays per year. Certainly this work schedule cannot be maintained for an extended period of time.

Because of the large amount of scatter in the data, the learning curves for the Shuttle processing flow data were difficult to define. The difference between the optimistic and pessimistic flight rate estimates is about one-third of the optimistic estimate. This is a large amount of uncertainty and does not inspire confidence.

Additionally, all of the caveats and assumptions presented in section I.D were such as to guarantee optimistic results from this analysis. Yet, to meet these estimates the Normal and Anomaly flow experience would both have to always progress at the most optimistic learning rates displayed. Therefore, we conclude that the analysis results show only marginal capability to meet the planned maximum sustained flight rate of 14 flights per year, and only if significant learning curve progress can be sustained and/or work schedules allowing few holidays and down weekends are used over long periods of time.

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CHAPTER VII

DEMOGRAPHIC MODELLING OF JSC

VII. DEMOGRAPHIC MODELLING OF JSC

1.0 INTRODUCTION

As the shuttle environment proceeds from its current status to a routine operational era, the organizational structure and duties and responsibilities of the supporting personnel must also undergo appropriate transition. The industrial interviews and literature survey support that one of the major barriers to smooth transition is poor employee demographics of the organization. Thus, it is necessary to characterize and analyze the composition of the AE, AM, CA, DA, EA, FA, GA, SA, TA, and VA offices regarding the age, grade, experience, starting age, and education of their professional employees. These organizations were chosen since they represent the bulk of the professional talent which is available to either manage or support the shuttle. The main purpose of this chapter is to provide a demographic analysis of JSC professional employees. This will help in modelling the necessary demographics required to achieve a smooth transition from an R/D to a routine operational era. This kind of survey is extremely important for JSC because changing demographics is a long lead time issue which must be monitored at regular intervals. Further, it will also help JSC in human resource planning, a vital issue for any organization operating in a routine operational environment. This type of survey and demographic analysis was also done in

the summers of 1984, 1985, 1986, and 1987. Appendix VII A shows the demographic state of NSTS as of the summer of 1988. Appendix VII B is a comparison of the 1984, 1985, 1986, 1987, and 1988 demographic studies. The method of data collection has become more refined as familiarity was gained with the problem. This makes some of the comparisons weak, while some of the comparisons are impossible. Specific instances of this problem are noted in the appendices.

2.0 CONCLUSIONS

The work force is old, experienced, high graded, and educated. All of these factors, while being necessary for R/D, will require extensive modelling before the shuttle can comfortably exist in an operational environment. While the key players for an operational era will certainly be pulled from this group and the operational era must be designed by this group, it is hard to imagine a worse demographic make up for an on going operational program. Other problems already discussed but worthy of managerial attention include the retirement problem and the high number of employees with grade 14 or better. Both of these problem need to be monitored on an annual basis. There are several trends worth mentioning that are beginning to emerge with the data. While these are contained in appendix VII B, they are included here for emphasis.

1. The size of the workforce is not a stable variable. A percent or so increase or decrease is common.

2. While the workforce is old, the average age variable is showing a steady, slow decline.

3. The size of the GS 13 spike is declining while the effect of retirements and new hires is showing up in the system.

4. Science and mathematics are showing a steady decline while engineering and business are increasing.

5. The percent of advanced degrees is showing increase after an early decline. The number of doctors degrees had a significant increase in 1988.

6. Engineering forms the largest part of the workforce except at the doctoral level where science leads.

As an observation, the demographics almost seem to indicate a reposturing of the workforce. The growth in the number of doctorates along with the lower grades and movement through the system hint at a restructuring. This may be by design or by accident. Either way, it seems healthy for the beginning of movement of the system to new tasks and challenges. Perhaps it is a new beginning.

3.0 RECOMMENDATIONS

The primary recommendation of this section is that the demographic analysis needs to be repeated in 1989. Other more specific recommendations and concerns are included in the appendices.

APPENDIX VII A

DEMOGRAPHIC SURVEY OF C, D, E, F, G, S, T, AND V ORGANIZATIONS PROFESSIONAL EMPLOYEES SUMMER 88

DEMOGRAPHIC SURVEY
C,D,E,F,G,S,T, AND V
ORGANIZATIONS
PROFESSIONAL EMPLOYEES
SUMMER 88
13 OCT JLH

INTRODUCTION AND OBJECTIVES:

This report is the first half of a two part report. The purpose of this half is to characterize as far as possible the makeup of the above offices regarding the age, grade, experience, starting age, and education of their professional employees. These offices were chosen to reflect the base which composes the current management and technical support for the shuttle program at JSC. The future needs of the program will also, more than likely, come from this base. As the shuttle flies again and becomes more stable on its path to a more operational era, human resource and manpower planning will be an essential ingredient in smoothing the transition. The intent of this document then, in simple terms, is to show the demographic state of NSTS and its support elements as of the summer of 1988.

As an aside, manpower planning for the shuttle is complicated by the fact that many of the upper level employees have been with NASA for long periods of time with a considerable number hiring on around the same point in time. Without careful planning, NASA could find itself stripped of upper level experience by both normal and early retirements over a short period of time.

This survey was also done in the summers of 84, 85, 86, and 87. The second half of this report which follows at a later date, is a comparison of these different surveys. Since the continuation of flight may prompt a series of retirements, a survey of this sort for next year is of particular importance. Since the planning changing of the demographics of an organization is a long lead time issue, a careful analysis of the demographic state and its trending seems to be necessary.

DEMOGRAPHICS:

The size of the sample in this survey was 1749. The rest of this report is devoted to a discussion of the charts presented.

AGE - CHARTS 1 AND 2

Chart 1 shows the age distribution in 5 year increments and is bimodal. The high point is the 46-50 year old bracket with a second peak at 26-30. This is different from what one expects with most organizations having a uni-modal distribution with a single peak at a younger age. This is however the typical JSC plot. The 46-50 peak is particularly

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bothersome since many of these people are approaching, if not already at, early retirement age. This will cause significant problems at some point in time, if for no other reason, that this group will reach retirement age at roughly the same time. This problem has the potential to become critical within the next several years.

Chart 2 shows the average age by grade and the average age (42.84 years) for all employees surveyed. For the predominant grades of 13 through SES there is approximately 4 years difference between the 13's and the 15's (46.4 to 50.3) and about 6 years between the 13's and the SES's (46.4 to 52.9). A significant dip occurs with the 12's through the 7's (34.3 to 26.0).

GRADE - CHART 3

Chart 3 shows the number by grade. The following is a percentage breakdown of the figures:

GD	SES	15	14	13	12	11	9	7	TOTAL
%	1.4	11.8	20.4	34.9	14.9	8.8	6.1	1.8	100.1
CUM%	1.4	13.2	33.6	68.5	83.4	92.2	98.3	100.1	

As a rough approximation, 1/3 of the employees are 14 or above, 1/3 are 13's, and 1/3 are 12 or less. Two problems surface as a result of these first 3 charts. One is that 1/3 of the employees are 14 or above and about 1/2 are 46 or older, directing attention to the retirement problem discussed earlier. Another is that the large number of high ranks may make promotion problems for the younger employees.

SERVICE - CHART 4

This chart shows the average years of service by grade. The 13 through 15 grades are essentially flat (18.4 through 21.8) with a small rise in service for SES (24.9). As would be expected, the 12 through 7 grades have appreciably less service. The average service for the sample was 15.7 years.

START AGE - CHARTS 5 AND 6

Chart 5 shows the start age for two year increments and Chart 6 shows the average start age for grade. Chart 5 illustrates that most people came to work for NASA in their 20's and Chart 6 shows that this property is fairly uniform throughout the grades.

COMBINED DEMOGRAPHICS - CHART 7

Chart 7 shows the age, service, and start age as a function of the grade. It is a summary of several of the preceding charts.

HIGHEST DEGREE - CHARTS 8, 9, AND 10

Highest degree refers to the highest degree earned. In this and all other degree comments, the doctors degree includes Ph.D.'s, M.D.'s, and D.D.S's.

Chart 8 shows the level of the highest degree with 69% BS, 20% MS, 9% DOC, and 3% with no degree. So 29% of the sample has a graduate degree indicating that the work force is highly educated.

Chart 9 shows the field and level of the highest degree with the largest component being a BS in engineering. Chart 10 shows the field of the highest degree with engineering comprising more than half of the degrees.

BS AS HIGHEST DEGREE - CHARTS 11 AND 12

For the employees for which the BS was the highest degree, Charts 11 and 12 show the field. Of the 1200 in the survey with a bachelors, engineering had 834 or 67%.

MS AS HIGHEST DEGREE - CHARTS 13 AND 14

These charts are similar to the two preceding except they show the information for the masters degree. Of the 347 masters degrees in the survey, engineering had 180 or 52% of the sample.

DOCTORS DEGREE - CHARTS 15 AND 16

Of the 152 doctors degrees, science was the largest with 102 (only 24 of which were in medicine) or 67%. Engineering was second largest with 30 or 20%.

FIELD AND LEVEL OF HIGHEST DEGREE - CHART 17

This chart is a composite chart of several which preceded it and shows the field and level of the highest degree.

CONCLUSIONS:

The work force is old, experienced, high graded, and educated. All of these factors, while being necessary for R/D, will require extensive modeling before the shuttle can comfortably exist in an operational environment. While the key players for an operational era will certainly be pulled from the group and the operational era must be designed by this group, it is hard to imagine a worse demographic make up for an on going operational program.

Other problems already discussed but worthy of managerial attention include the retirement problem and the high number of employees with grade 14 or better. Both of these problems need to be monitored on an annual basis.

AGE DISTRIBUTION
SUMMER 1988

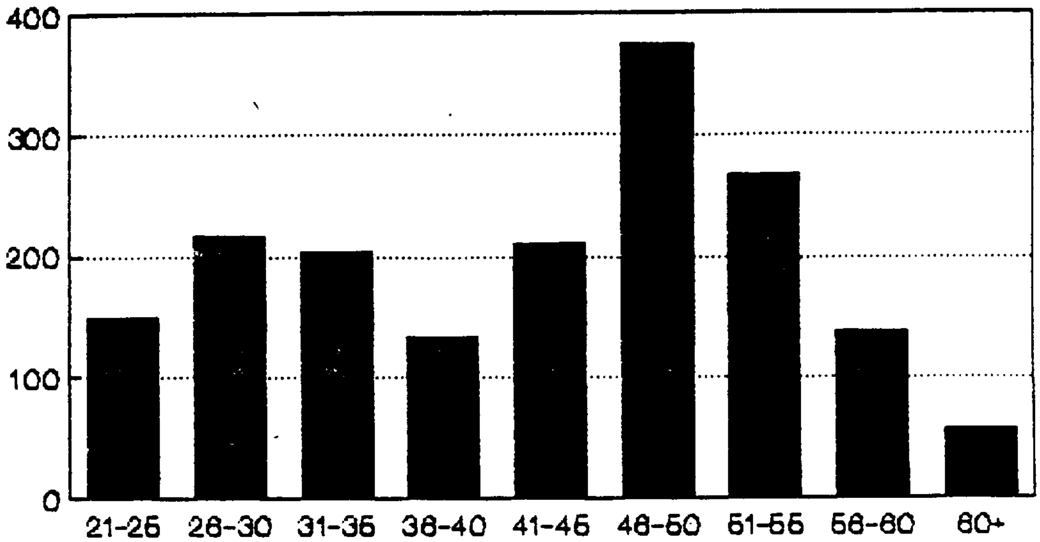

CHART 1

AVERAGE AGE BY GS
SUMMER 88

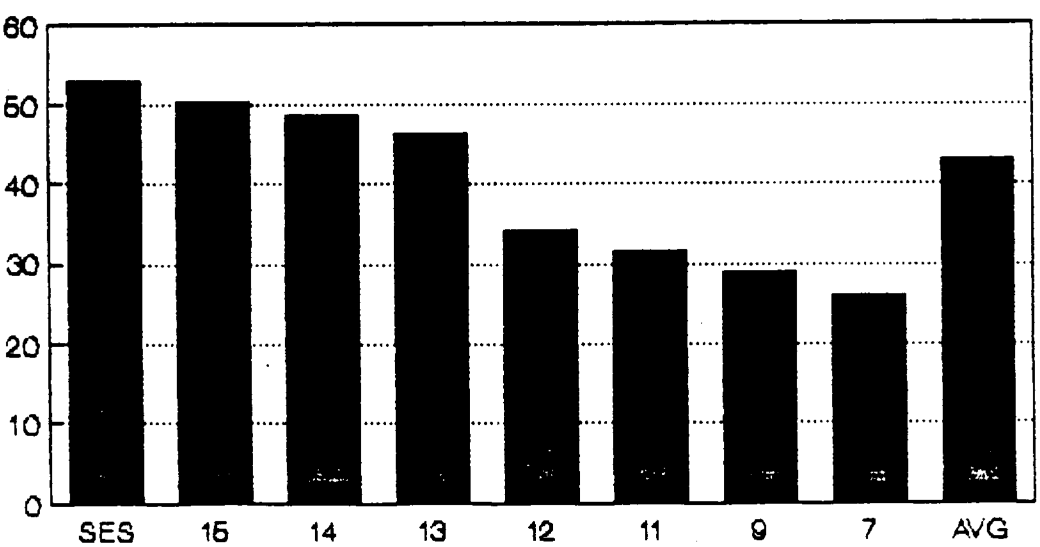

CHART 2

NUM. BY GRADE
SUMMER 1988

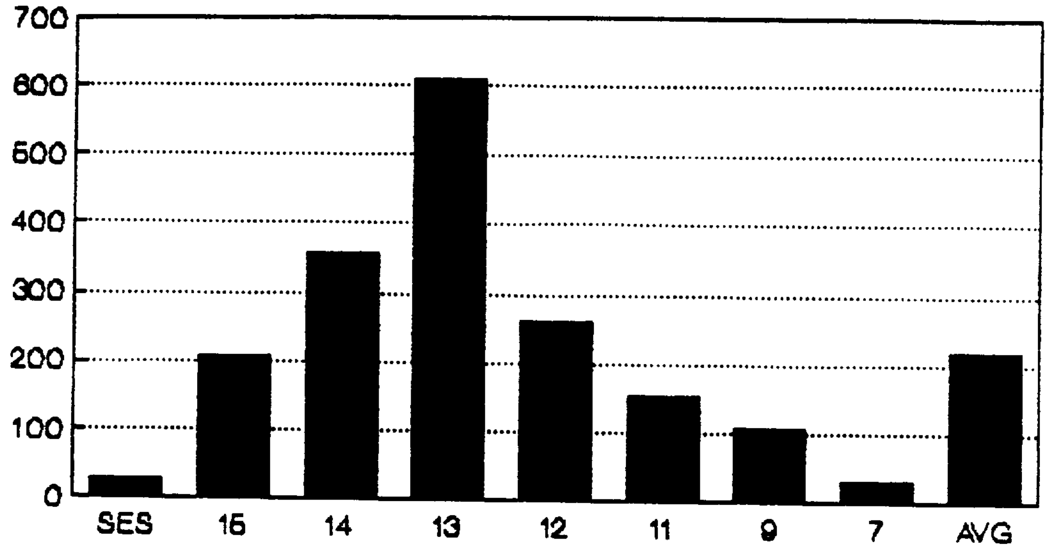

CHART 3

AVG SERVICE BY GD
SUMMER 1988

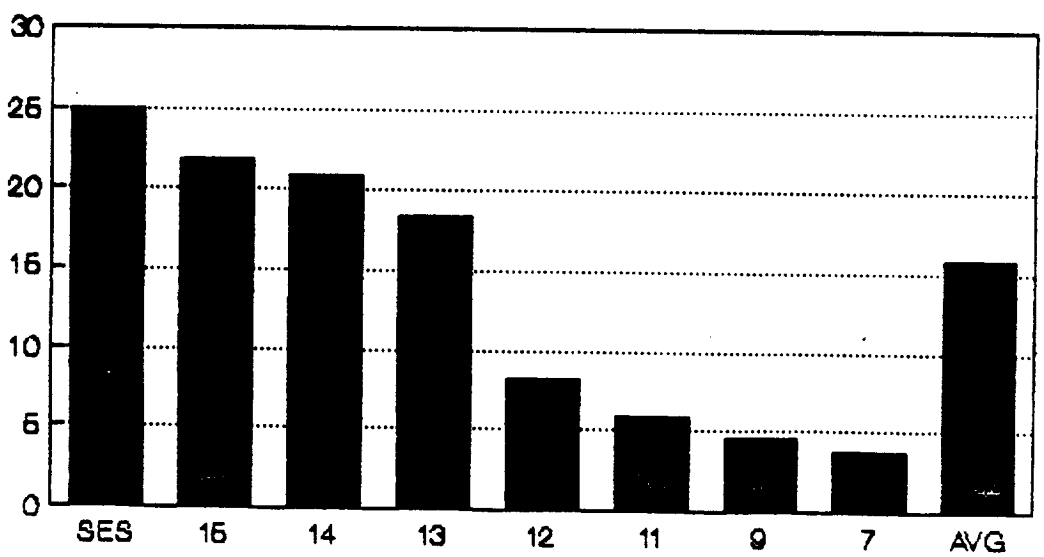

CHART 4

START AGE
SUMMER 1988

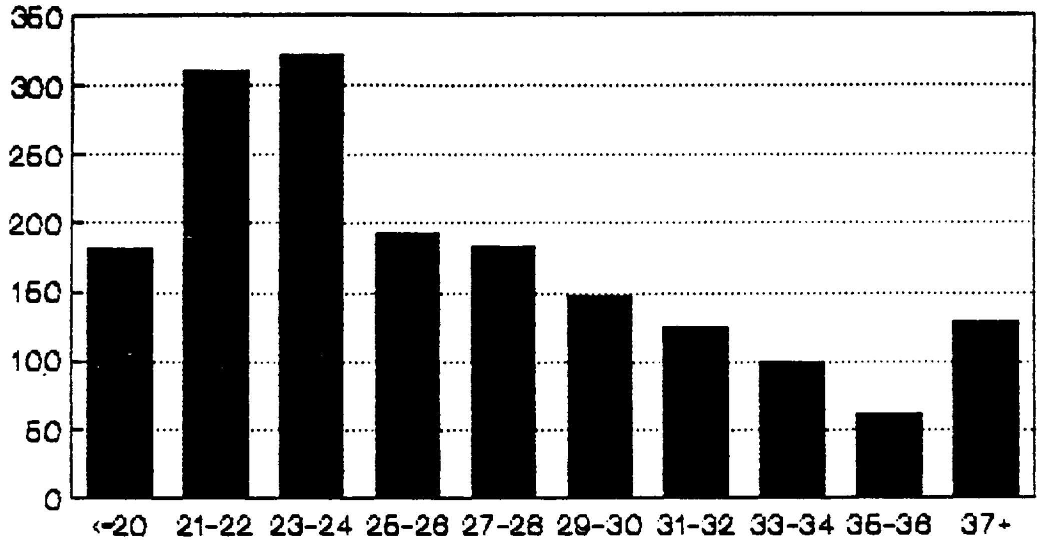

CHART 5

AVG START AGE
SUMMER 1988

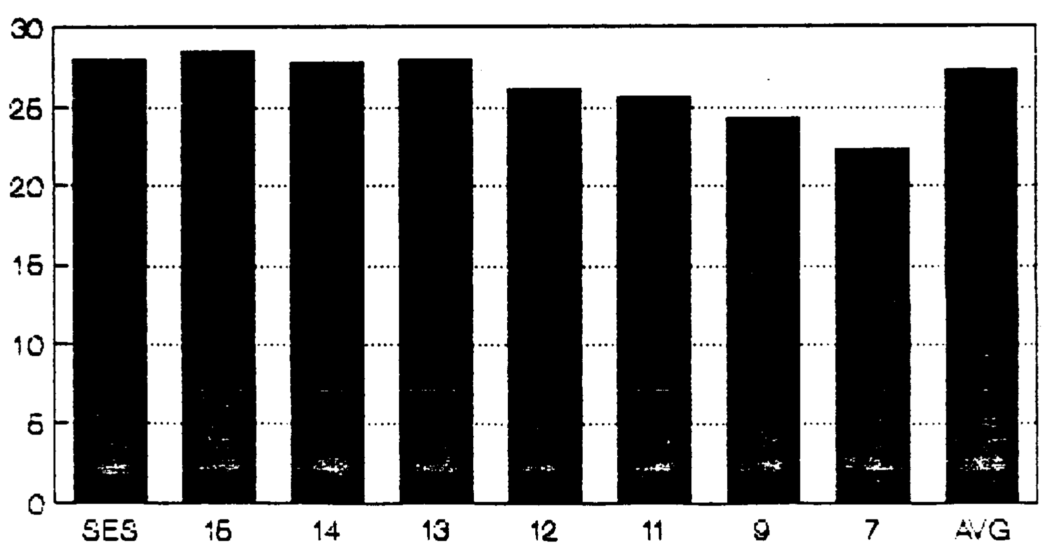

CHART 6

AGE/SERVICE/START AGE/GD
SUMMER 1988

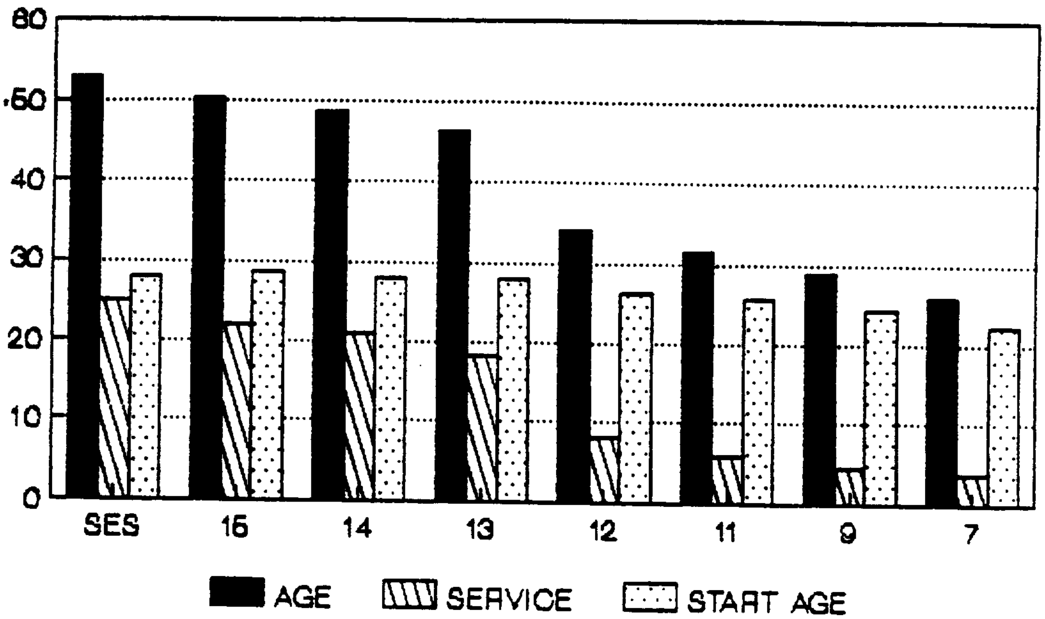

CHART 7

HIGHEST DEGREE LEVEL
SUMMER 1988

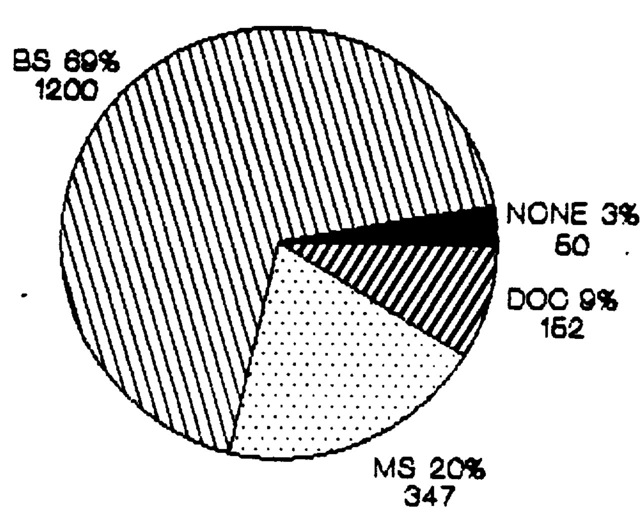

CHART 8

FIELD OF HIGHEST DEGREE
SUMMER 1988

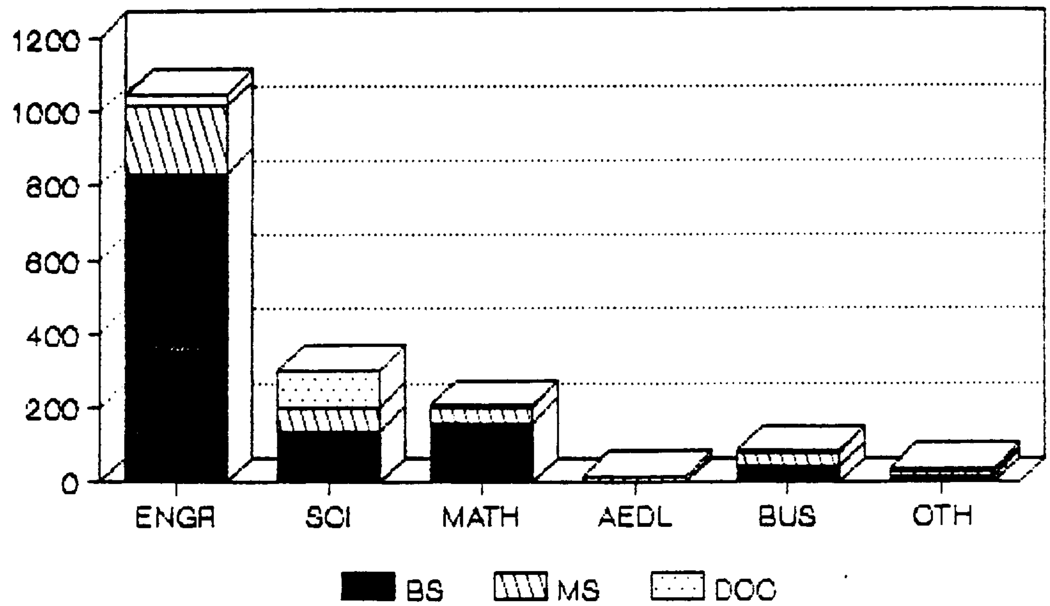

CHART 9

FIELD OF HIGHEST DEGREE
SUMMER 1988

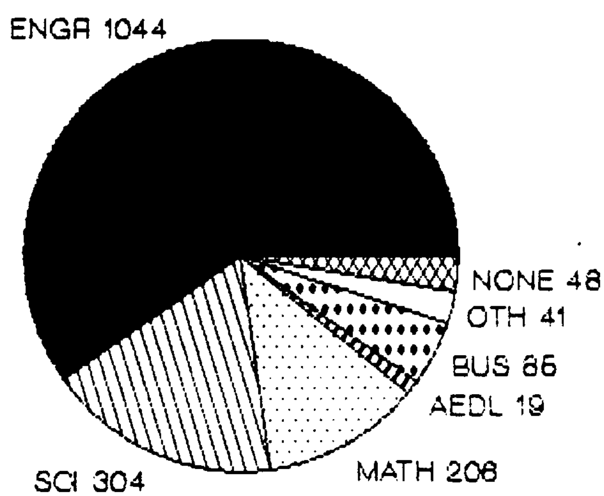

CHART 10

FIELD OF BS DEGREE
AS HIGH DEGREE
SUMMER 1988

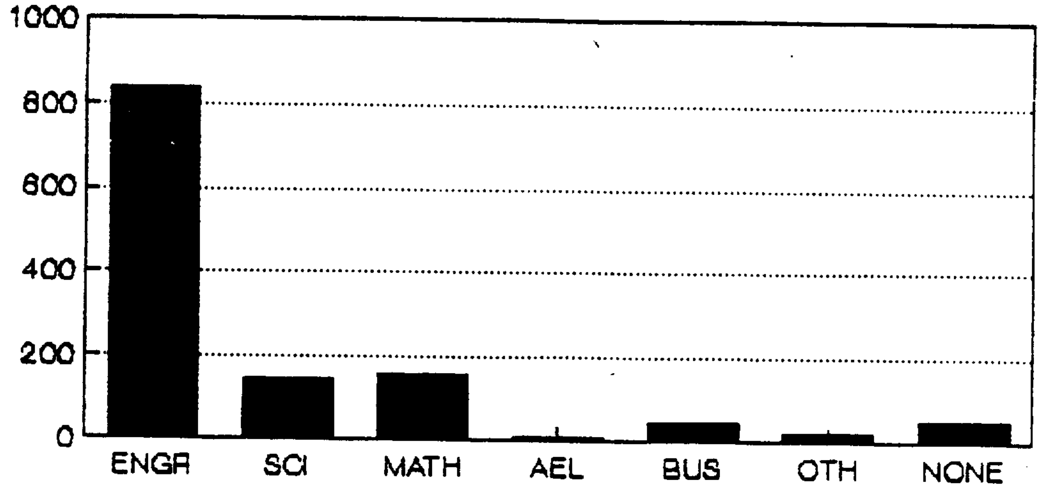

CHART 11

FIELD OF BS DEGREE
AS HIGH DEGREE
SUMMER 1988

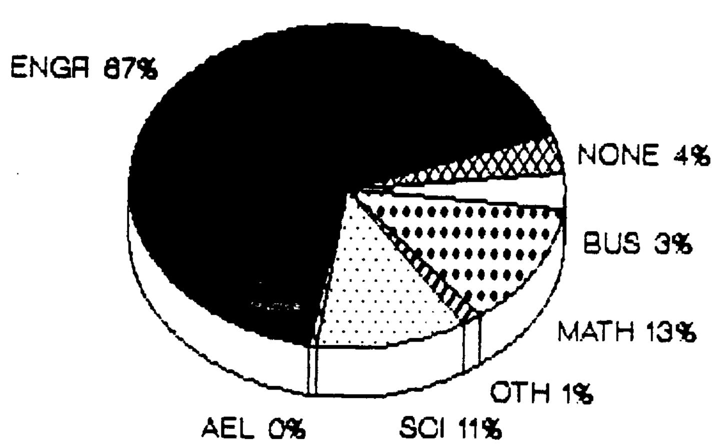

CHART 12

FIELD OF MS DEGREE
AS HIGH DEGREE
SUMMER 1988

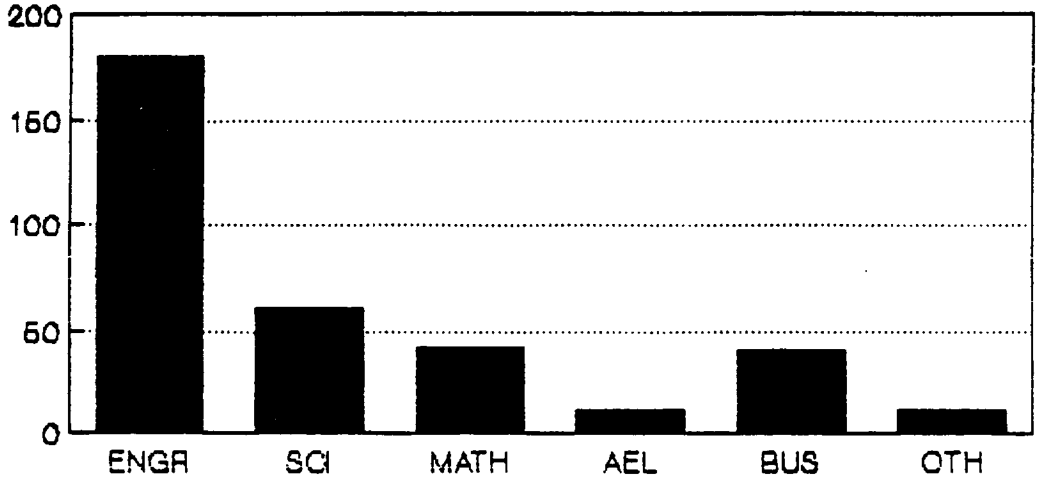

CHART 13

FIELD OF MS DEGREE
AS HIGH DEGREE
SUMMER 1988

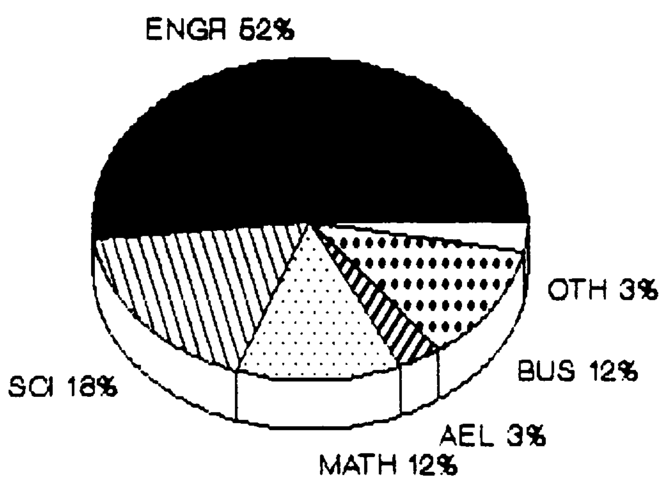

CHART 14

FIELD OF DOCTOR'S DEG
AS HIGH DEGREE
SUMMER 1988

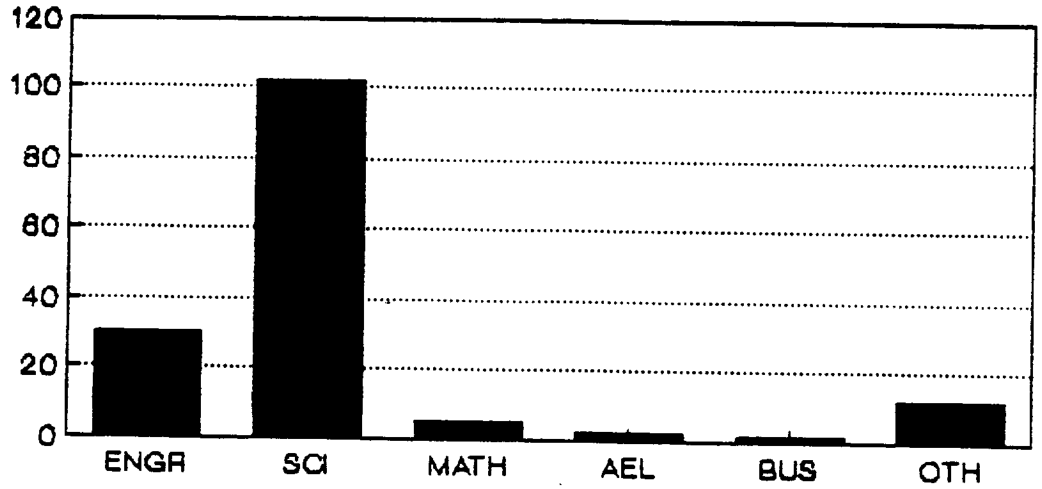

CHART 15

FIELD OF DOCTOR'S DEG
AS HIGH DEGREE
SUMMER 1988

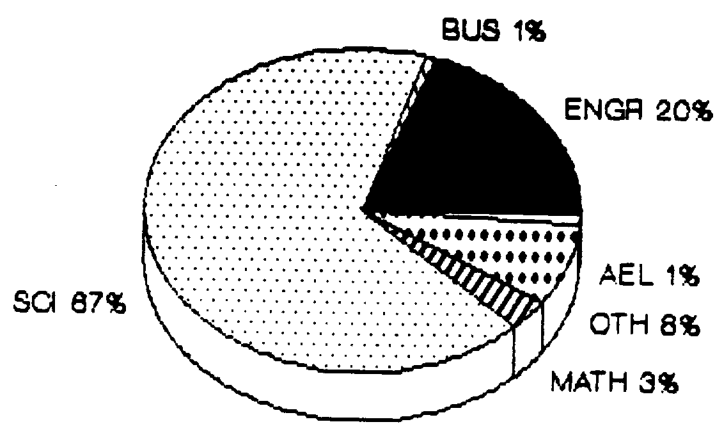

CHART 16

DEGREES BY FIELD
AND LEVEL
SUMMER 1988

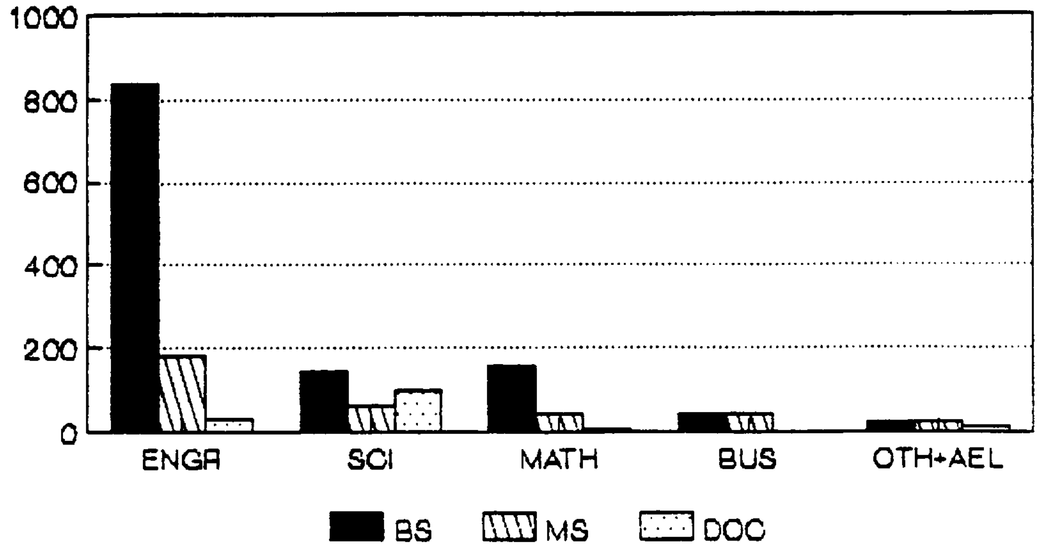

CHART 17

APPENDIX VII B

DEMOGRAPHIC COMPARISION

1984-1988

DEMOGRAPHIC COMPARISON
1984-1988

JLH JAN 89

INTRODUCTION:

In the summers of 1984 through 1988 studies were done on the composition of the work force at JSC that had a strong probability of being involved in the management of the shuttle program. The following table shows the specific offices by year.

1984-85	1986-88
AM space operations	AM space operations
AE research and engineering	AE research and engineering
CA flight crew operations	CA flight crew operations
DA mission operations	DA mission operations
EA engineering	EA engineering
FA mission support	FA mission support
SA space and life sciences	SA space and life sciences
LA NSTS program office	GA NSTS system office
MA space shuttle projects	VA orbiter projects office
	TA NSTS integration/operations

While the names changed somewhat in 1986 due to a reorganization of the NSTS program and project offices, the people and the actual working positions surveyed stayed the same.

This report is the second half of a report finished earlier which showed an in-depth look at the 1988 offices and, as such, serves as a continuation of that report. One difficulty encountered in the preparation of a comparison was that the means of collecting the data has changed since 1984 as familiarity has been gained with the problem. This made some comparisons over the entire span of 84-88 weak and even made a few others impossible. Specific instances of this problem will be mentioned as the data is discussed. In addition, some of the data in the yearly reports does not seem to have much value when analyzed for change. Degree migration is a specific incidence of this last consideration.

RESULTS:

A. Number

Year:	1984	1985	1986	1987	1988
Sample Size:	1731	1764	1689	1770	1749

The changes in 84-85 and 85-86 may well be due to reorganizations which occurred during those time periods. The change from 86 to 87 seems to be due to new hires with

the GS-11 grade showing significant growth from 125 to 162 (Table 2). The decrease in 88 is perhaps due to retirements with the higher grades showing losses. As the flight rate grows, there may well be additional losses in the higher grade cohorts.

B. Age

Table one gives the age by five year increments and shows the change between the years. Chart one gives the same information graphically. The comparison of the 85 data to the 86, 87, and 88 data may be spurious at best since the data in 85 was drawn by GS grade within an office and in the other years was drawn as a pure variable. The 85 method had the disadvantage of smoothing out extremes.

An observation worth noting is that the average age variable is slowly decreasing. This is perhaps due to a combination of retirements and new hires.

C. Number by grade

Tables 2 and 3 show the number and percent of employees by GS grade. Charts 2 through 8 present the same information in a graphic format. Charts 7 and 8 perhaps present the comparative information best.

As a percent of the total sample, the GS 13 spike is slowly declining (Chart 8). The number of GS 13's has also declined from the high in 84 (Chart 7). GS 11's have also shown a percent decline, GS 12's a percent increase, while the other grades have either show a slight increase or remained much the same over the 87 values. The magnitude of GS 12's and GS 9's has also shown an increase perhaps indicating new hires and movement up the system. Note that the upper grades of GS 13 through SES show declines that there is some movement out of the system, i.e., retirements.

D. Number by field of highest degree

Tables 4 and 5 show the number and percent of employees by the field of their highest degree. Charts 9 and 10 are the graphical representation of the same information. Note that in these tables and charts and the ones that follow, A/ED/L stands for arts, education, and law. The other category represents trace elements of degrees which did not fit into other categories.

Engineering and business have shown a steady percent growth while science and math have shown a steady percent decline. Could this perhaps be interpreted as a loss of creative talent and a growth of developmental and bureaucratic talent? Under any interpretation, 5% of the workforce, noted for its creativity, being business majors is worth mention.

E. Number by degree level

Tables 6 and 7 show the number of employees by the level of their highest degree earned, by both number and percent. Charts 11, 12A, and 12B are the graphic interpretations of the same information. While there was an increase in the doctoral cohort, by both percent and number, there was a decrease in the master's and bachelor's. Perhaps the increase in the doctors is due to new hires. The following shows the number of advanced degrees, masters or higher, for each of the years:

Year	1984	1985	1986	1987	1988
Number of Advanced Degrees	472	468	456	491	499
Percent of Advanced Degrees	27.3%	26.5%	27.0%	27.7%	28.6%

Note that 1988 shows a significant increase over 1987. Perhaps this increase is advanced degrees will help to offset the loss of creative talent mentioned in the previous section.

F. Number by field and level

Table 8 along with charts 12A, 12B, and 12C show the number and percent by both field and level.

Engineering has the largest amount of bachelors and masters degrees with science and mathematics running distant seconds. With doctors degrees, science has a significant lead with engineering a distant second and trace elements of mathematics. Note that all three of these fields showed a growth in doctors in going from 87 to 88 and a decline in masters and bachelors. Another observation worth mention is the steady decline (shown in the totals portion of Table 8) of the scientists and mathematicians along with the steady increase of the business majors.

CONCLUSIONS:

There are several trends worth mentioning that are beginning to emerge with the data.

1. The size of the workforce is not a stable variable. A percent or so increase or decrease is common.

2. While the workforce is old, the average age variable is showing a steady, slow decline.

3. The size of the GS 13 spike is declining while the effect of retirements and new hires is showing up in the system.

4. Science and mathematics are showing a steady decline

while engineering and business are increasing.

5. The percent of advanced degrees is showing increase after an early decline. The number of doctors degrees had a significant increase in 1988.

6. Engineering forms the largest part of the workforce except at the doctoral level where science leads.

As an observation, the demographics almost seem to indicate a reposturing of the workforce. The growth in the number of doctorates along with the lower grades and movement through the system hint at a restructuring. This may be by design or by accident. Either way, it seems healthy for the beginning of movement of the system to new tasks and challenges. Perhaps it is a new beginning.

RECOMMENDATIONS:

1. Care should be used to insure that the amount of higher level talent, from an educational standpoint, is distributed throughout the fields in a manner which best meets the needs of the organization. The growth of the percent of business majors, as an example, deserves attention.

2. The impact of new hires and retirements needs to be observed closely. A needs analysis, along with a study on attrition, seems to be in order.

3. The GS 13 spike needs continued monitoring.

4. This study needs to be repeated in 1989.

AGE COMPARISON: 85 THROUGH 88
SUMMER 88

AGE	85	86	87	88
21-25	70	117	141	148
26-30	116	192	204	217
31-35	164	142	176	204
36-40	59	105	109	133
41-45	324	308	279	210
46-50	783	386	393	375
51-55	218	270	293	267
56-60	21	115	119	138
61+	4	54	57	57
AVG	43.6	43.6	43.4	42.8

NOTE: During the summer of 85, the age was gathered on an average age for GS grade within an office. For the summers of 86 through 88, the age was gathered as a pure variable. This accounts for the large delta difference within several of the age cohorts. The gathering method of 85 had the effect of smoothing out the extremes. For these reasons great care must be used in interpreting the data presented here and in the histogram that involves 85 ages.

AGE	86-85	87-86	87-85	88-87	88-86	88-85
21-25	47	24	71	7	31	78
26-30	76	12	88	13	25	101
31-35	-22	34	12	28	62	40
36-40	46	4	50	24	28	74
41-45	-16	-29	-45	-69	-98	-114
46-50	-397	7	-390	-18	-11	-408
51-55	52	23	75	-26	-3	49
56-60	94	4	98	19	23	117
61+	50	3	53	0	3	53
AVG	0	-0.2	-0.2	-0.6	-0.8	-0.8

TABLE 1

AGE COMPARISON:85-88
SUMMER 88

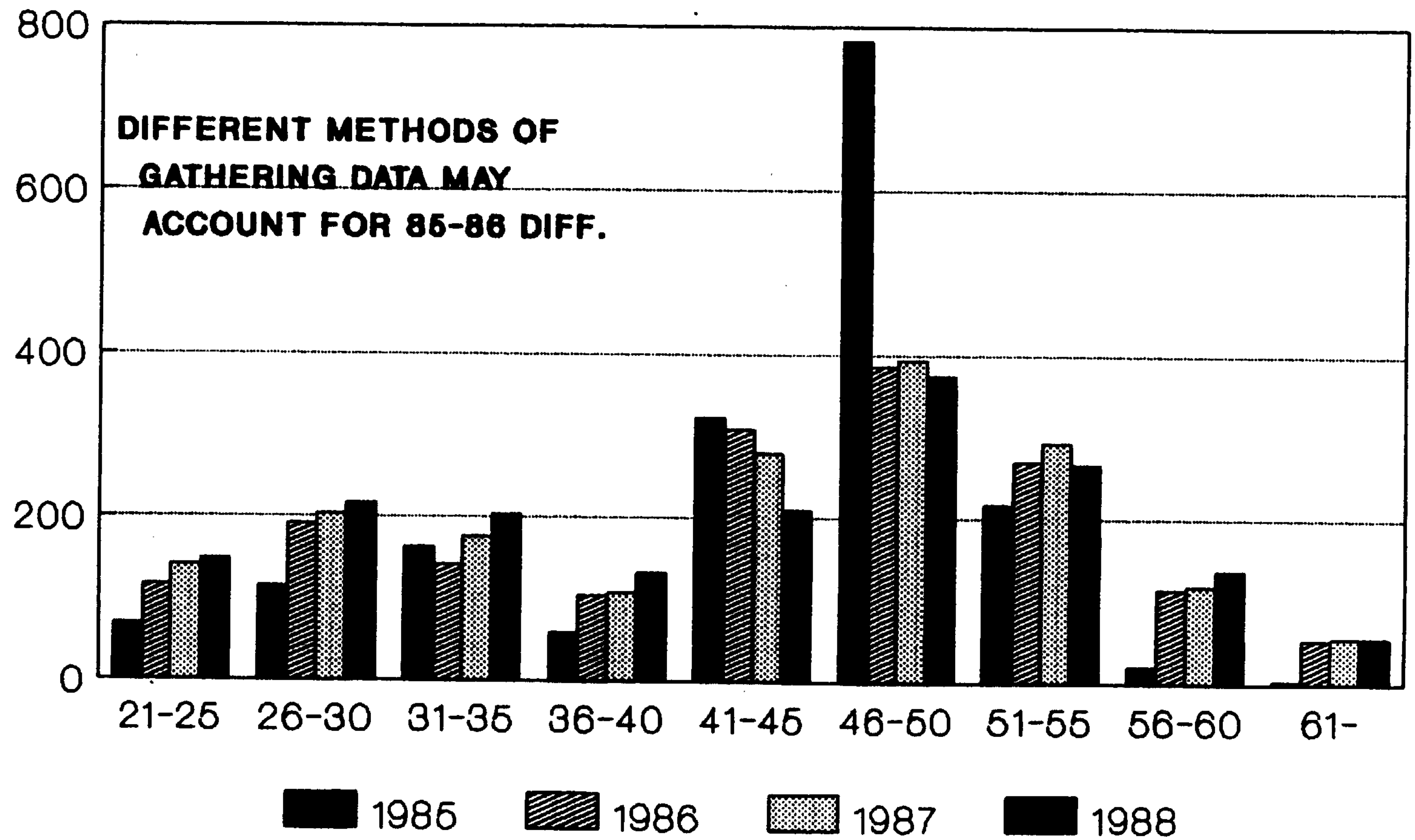

CHART 1

GS GRADES COMPARISON: 84, 85, 86, 87, AND 88
SUMMER 88

GRADE	1984	1985	1986	1987	1988
SES	31	25	27	28	24
15	174	199	208	213	206
14	313	330	355	362	356
13	771	729	628	643	610
12	256	233	214	243	261
11	80	106	125	162	154
9	56	77	96	84	107
7	50	65	36	35	31
TOTAL	1731	1764	1689	1770	1749

TABLE 2.

PERCENT OF EMPLOYEES BY GS GRADE

GRADE	84	85	86	87	1988
SES	1.8%	1.4%	1.6%	1.6%	1.4%
15	10.1%	11.3%	12.3%	12.0%	11.8%
14	18.1%	18.7%	21.0%	20.5%	20.4%
13	44.5%	41.3%	37.2%	36.3%	34.9%
12	14.8%	13.2%	12.7%	13.7%	14.9%
11	4.6%	6.0%	7.4%	9.2%	8.8%
9	3.2%	4.4%	5.7%	4.7%	6.1%
7	2.9%	3.7%	2.1%	2.0%	1.8%
TOTAL	100%	100%	100%	100%	100%

TABLE 3

GRADE 1984

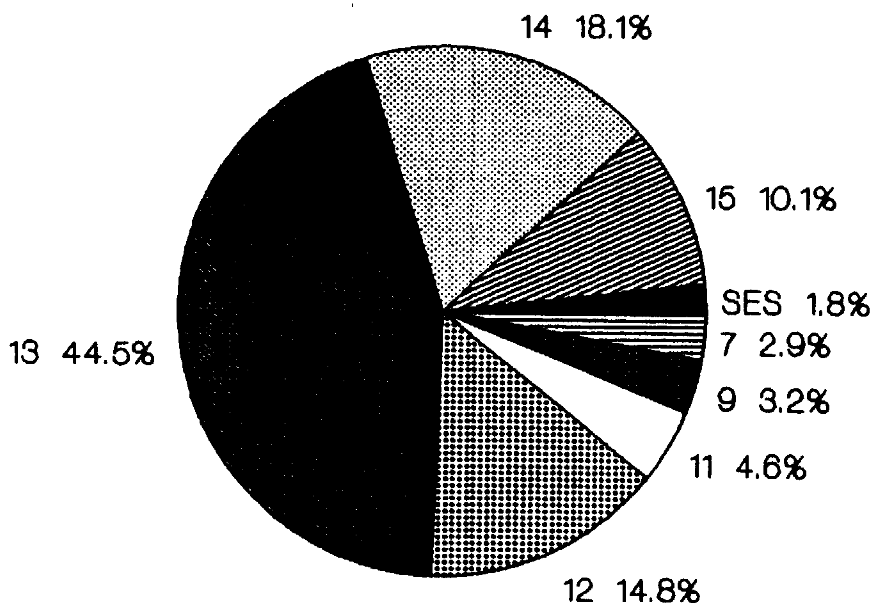

CHART 2

GRADE 1985

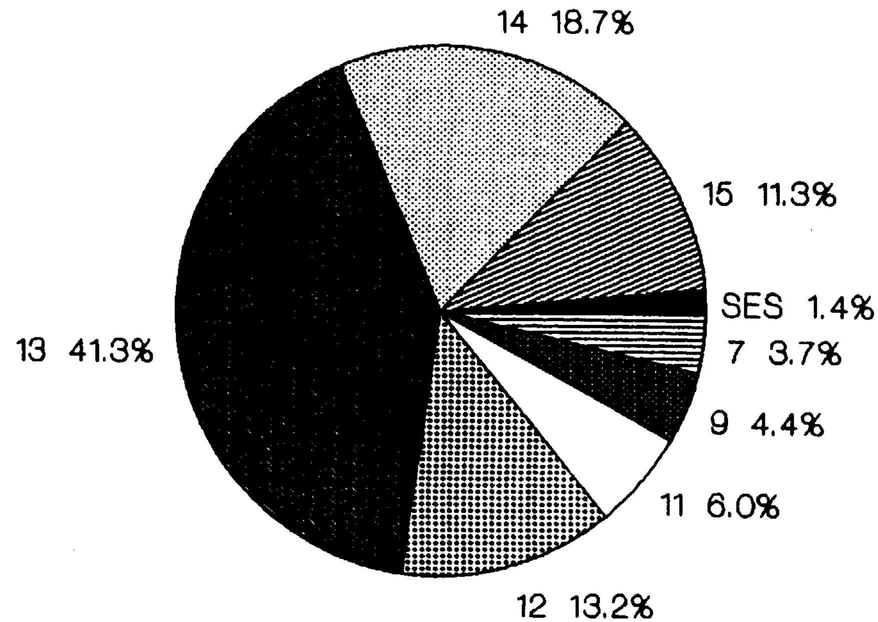

CHART 3

GRADE 1986

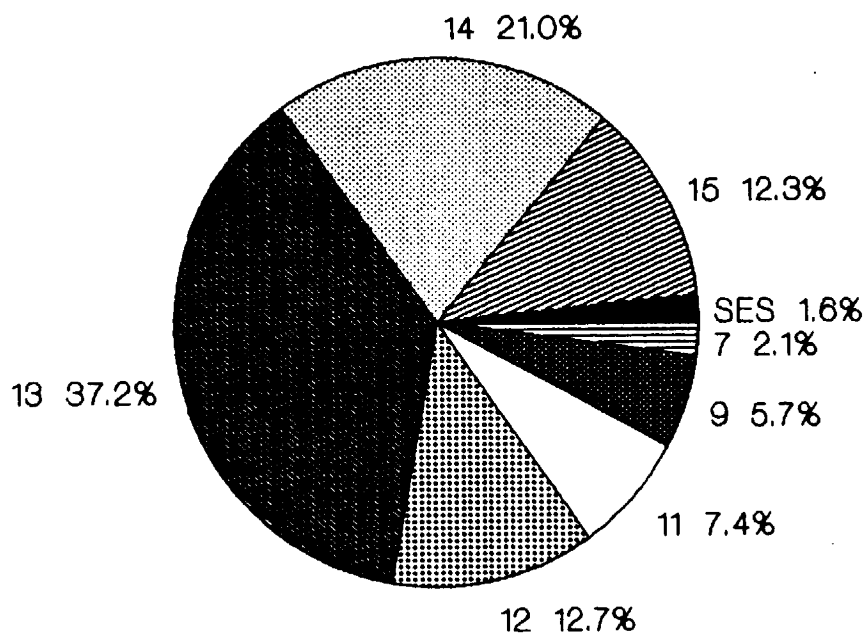

CHART 4

GRADE 1987

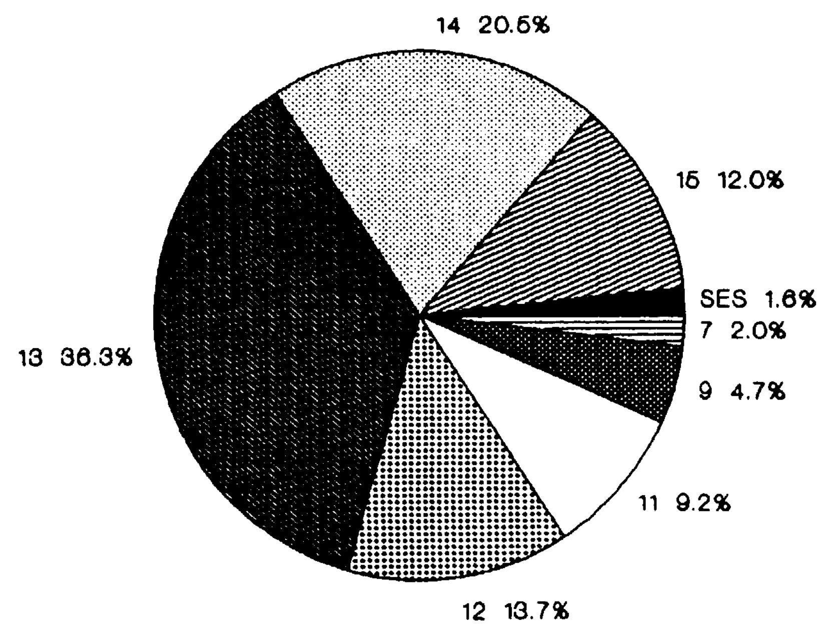

CHART 5

GRADE 1988

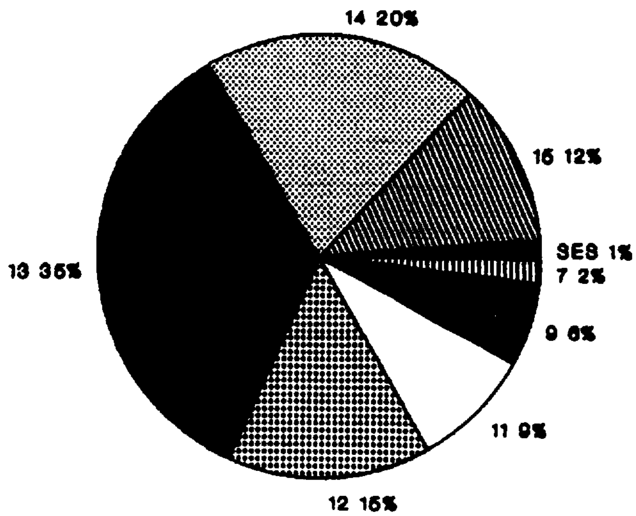

CHART 6

GS GRADE COMPARISON FOR 84-88
NUMBER BY GRADE: SUMMER 88

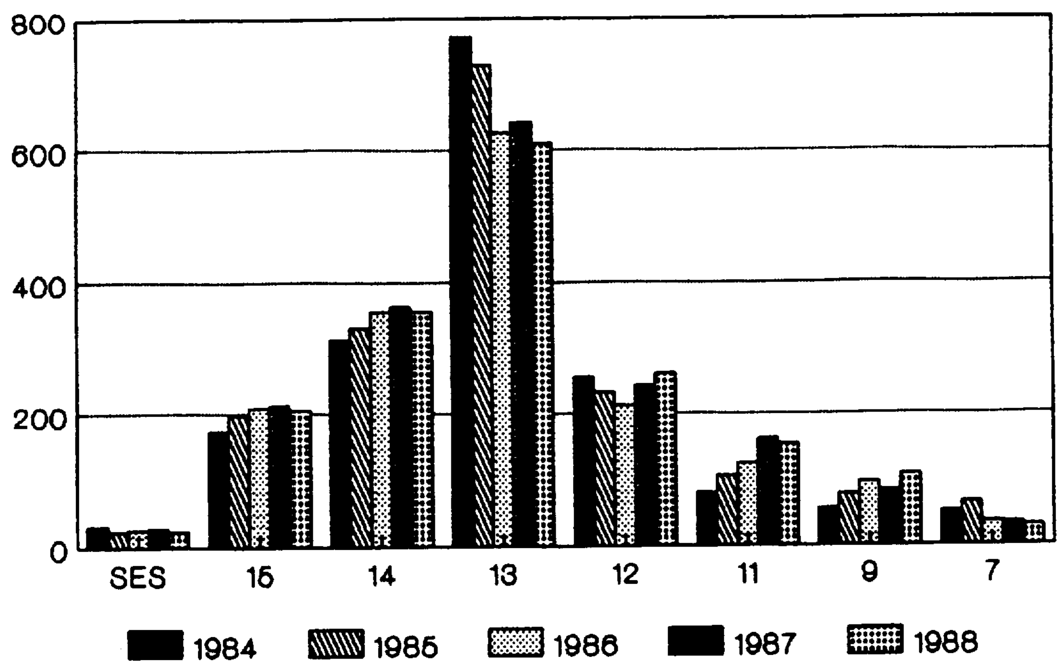

CHART 7

GS GRADE COMPARISON FOR 84-88
PERCENT BY GRADE: SUMMER 88

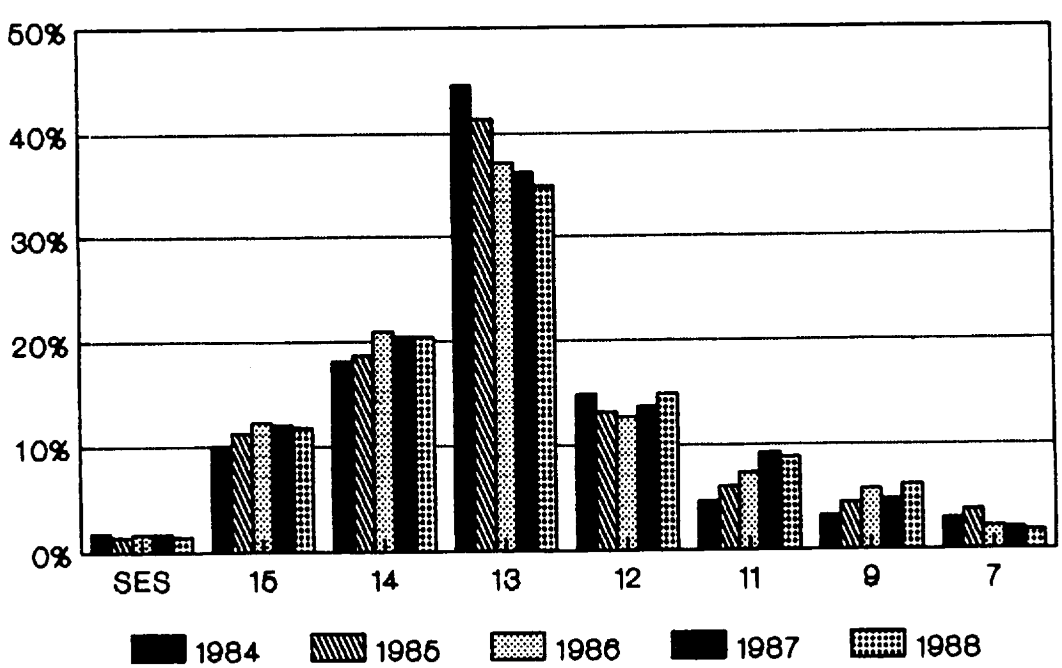

CHART 8

NUMBER OF EMPLOYEES BY FIELD OF HIGHEST DEGREE

DEGREE	ENGR	SCI	MATH	A/ED/L	BUS	OTHER	NONE	SUM
1984	1000	345	247	20	42	30	48	1732
1985	1038	333	240	16	63	24	50	1764
1986	993	321	217	15	70	26	47	1689
1987	1043	326	216	18	82	36	50	1771
1988	1044	304	206	19	85	41	48	1747

TABLE 4

PERCENT OF EMPLOYEES BY FIELD OF HIGHEST DEGREE

DEGREE	ENGR	SCI	MATH	A/ED/L	BUS	OTHER	NONE	SUM
1984	57.7%	19.9%	14.3%	1.2%	2.4%	1.7%	2.8%	100.0%
1985	58.8%	18.9%	13.6%	0.9%	3.6%	1.4%	2.8%	100.0%
1986	58.8%	19.0%	12.8%	0.9%	4.1%	1.5%	2.8%	100.0%
1987	58.9%	18.4%	12.2%	1.0%	4.6%	2.0%	2.8%	100.0%
1988	59.8%	17.4%	11.8%	1.1%	4.9%	2.3%	2.7%	100.0%

TABLE 5

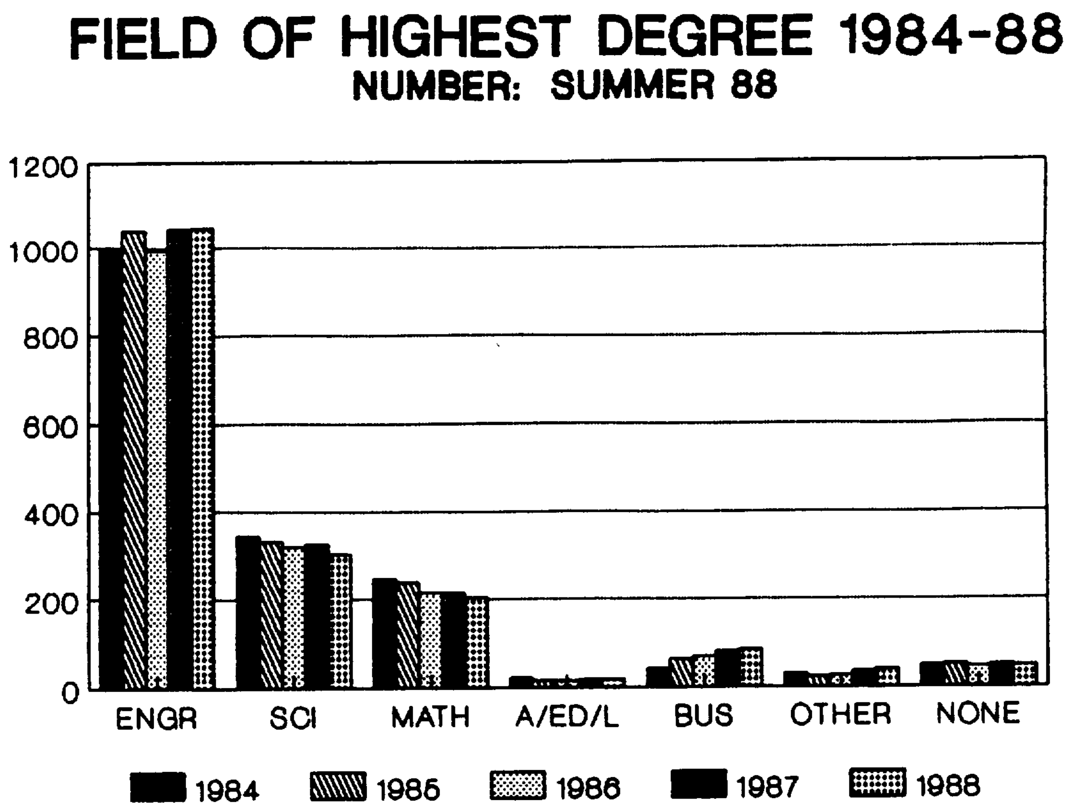

CHART 9

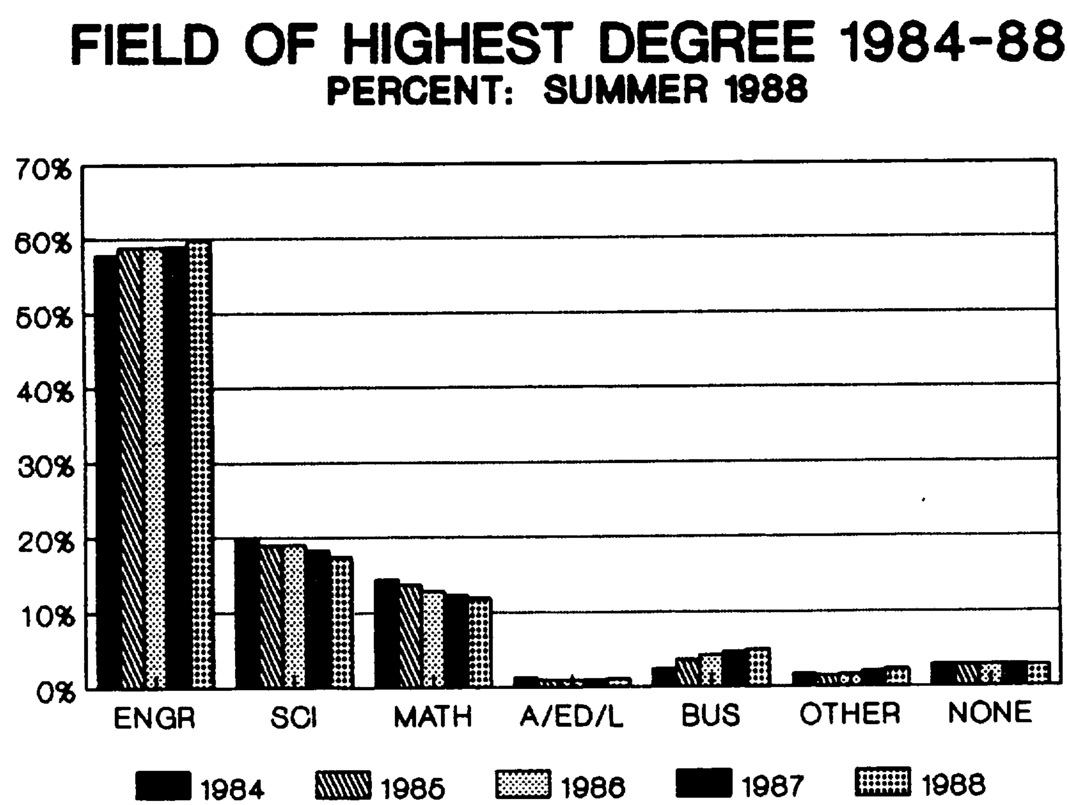

CHART 10

NUMBER OF EMPLOYEES BY DEGREE LEVEL

YEAR	DOCTORS	MASTERS	BACHELOR	NONE	SUM
1984	138	334	1209	51	1732
1985	138	330	1248	48	1764
1986	133	323	1183	50	1689
1987	137	354	1224	56	1771
1988	152	347	1200	48	1747

TABLE 6

PERCENT OF EMPLOYEES BY DEGREE LEVEL

YEAR	DOCTORS	MASTERS	BACHELOR	NONE	SUM
1984	8.0%	19.3%	69.8%	2.9%	100.0%
1985	7.8%	18.7%	70.7%	2.7%	100.0%
1986	7.9%	19.1%	70.0%	3.0%	100.0%
1987	7.7%	20.0%	69.1%	3.2%	100.0%
1988	8.7%	19.9%	68.7%	2.7%	100.0%

TABLE 7

NUMBER BY DEGREE LEVEL
SUMMER 1988

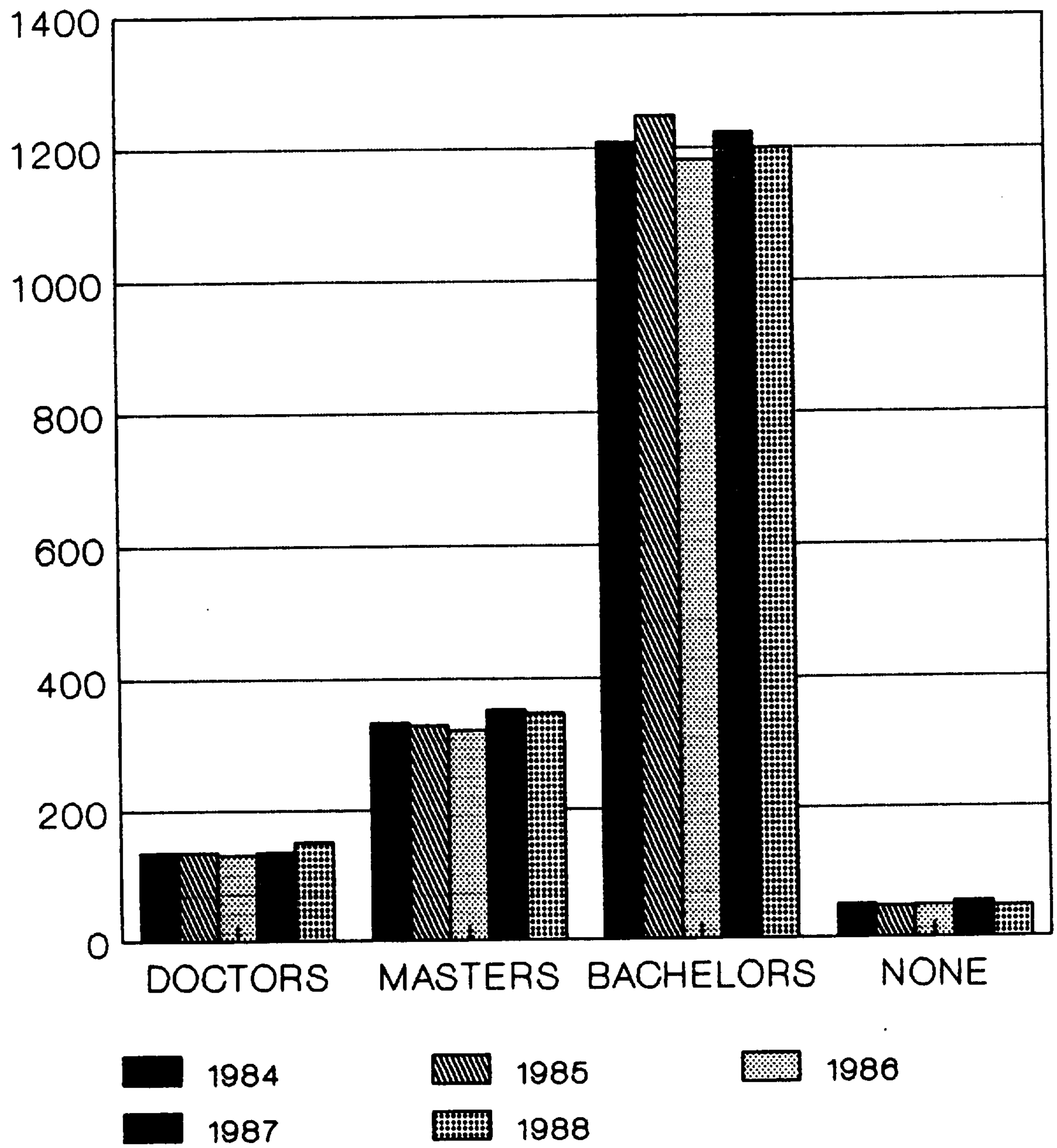

CHART 11

DEGREES BY FIELD AND LEVEL: 1985 TO 1988

		ENGR	SCI	MATH	A/E/L	BUS	OTH	TOTAL	NONE
BACHELOR	1985	839	176	190	8	24	11	1248	48
	1986	808	163	168	6	26	12	1183	50
	1987	835	162	168	6	38	15	1224	56
	1988	834	141	158	6	43	18	1200	48
MASTERS	1985	170	63	46	8	38	5	330	
	1986	162	62	45	8	41	5	323	
	1987	183	64	44	10	41	12	354	
	1988	180	61	43	11	41	11	347	
DOCTORS	1985	29	96	4	0	1	8	138	
	1986	23	96	4	1	1	8	133	
	1987	25	99	4	2	1	8	139	
	1988	30	102	5	2	1	12	152	
TOTALS	1985	1038	335	240	16	63	24	1716	1764
	1986	993	321	217	15	68	25	1639	1689
	1987	1043	325	216	18	80	35	1717	1773
	1988	1044	304	206	19	85	41	1699	1747

TABLE 8

DEGREES BY FIELD AND LEVEL: 1985 TO 1988
AS PERCENT OF WORKFORCE IN A GIVEN YEAR

		ENGR	SCI	MATH	A/E/L	BUS	OTH	TOTAL	NONE
BACHELOR	1985	47.6%	10.0%	10.8%	0.5%	1.4%	0.6%	70.7%	2.7%
	1986	47.8%	9.7%	9.9%	0.4%	1.5%	0.7%	70.0%	3.0%
	1987	47.1%	9.1%	9.5%	0.3%	2.1%	0.8%	69.0%	3.2%
	1988	47.7%	8.1%	9.0%	0.3%	2.5%	1.0%	68.7%	2.7%
MASTERS	1985	9.6%	3.6%	2.6%	0.5%	2.2%	0.3%	18.7%	
	1986	9.6%	3.7%	2.7%	0.5%	2.4%	0.3%	19.1%	
	1987	10.3%	3.6%	2.5%	0.6%	2.3%	0.7%	20.0%	
	1988	10.3%	3.5%	2.5%	0.6%	2.3%	0.6%	19.9%	
DOCTORS	1985	1.6%	5.4%	0.2%	0.0%	0.1%	0.5%	7.8%	
	1986	1.4%	5.7%	0.2%	0.1%	0.1%	0.5%	7.9%	
	1987	1.4%	5.6%	0.2%	0.1%	0.1%	0.5%	7.8%	
	1988	1.7%	5.8%	0.3%	0.1%	0.1%	0.7%	8.7%	
TOTALS	1985	58.8%	19.0%	13.6%	0.9%	3.6%	1.4%	97.3%	100.0%
	1986	58.8%	19.0%	12.8%	0.9%	4.0%	1.5%	97.0%	100.0%
	1987	58.8%	18.3%	12.2%	1.0%	4.5%	2.0%	96.8%	100.0%
	1988	59.8%	17.4%	11.8%	1.1%	4.9%	2.3%	97.3%	100.0%

TABLE 9

DEGREE BY FIELD AND LEVEL (A)

1985 TO 1988
BS DEGREES

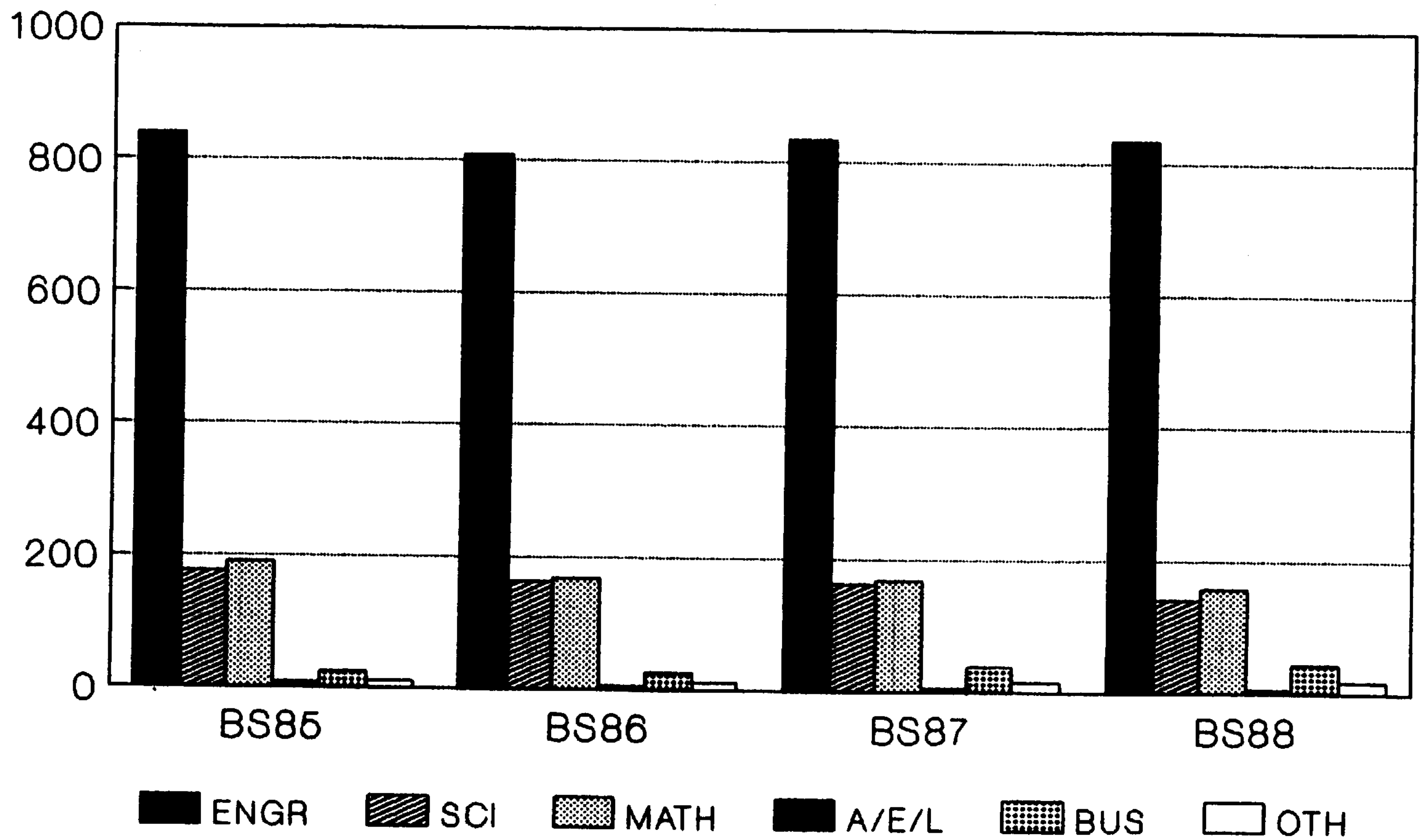

CHART 12 (A)

DEGREE BY FIELD AND LEVEL (B)
1985 TO 1988
MS DEGREES

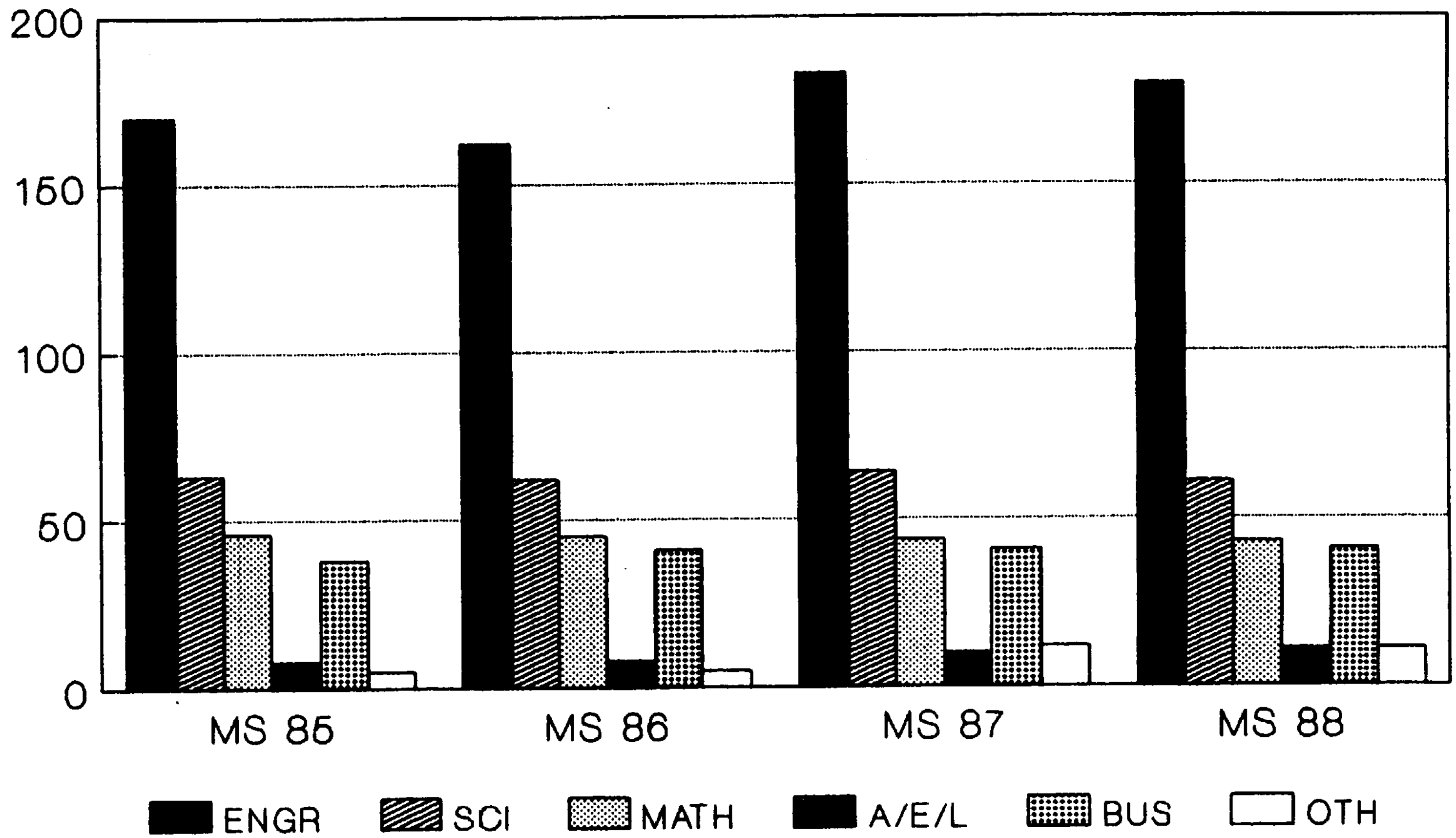

CHART 12 (B)

DEGREE BY FIELD AND LEVEL (C)
1985 TO 1988
DOCTOR'S DEGREES

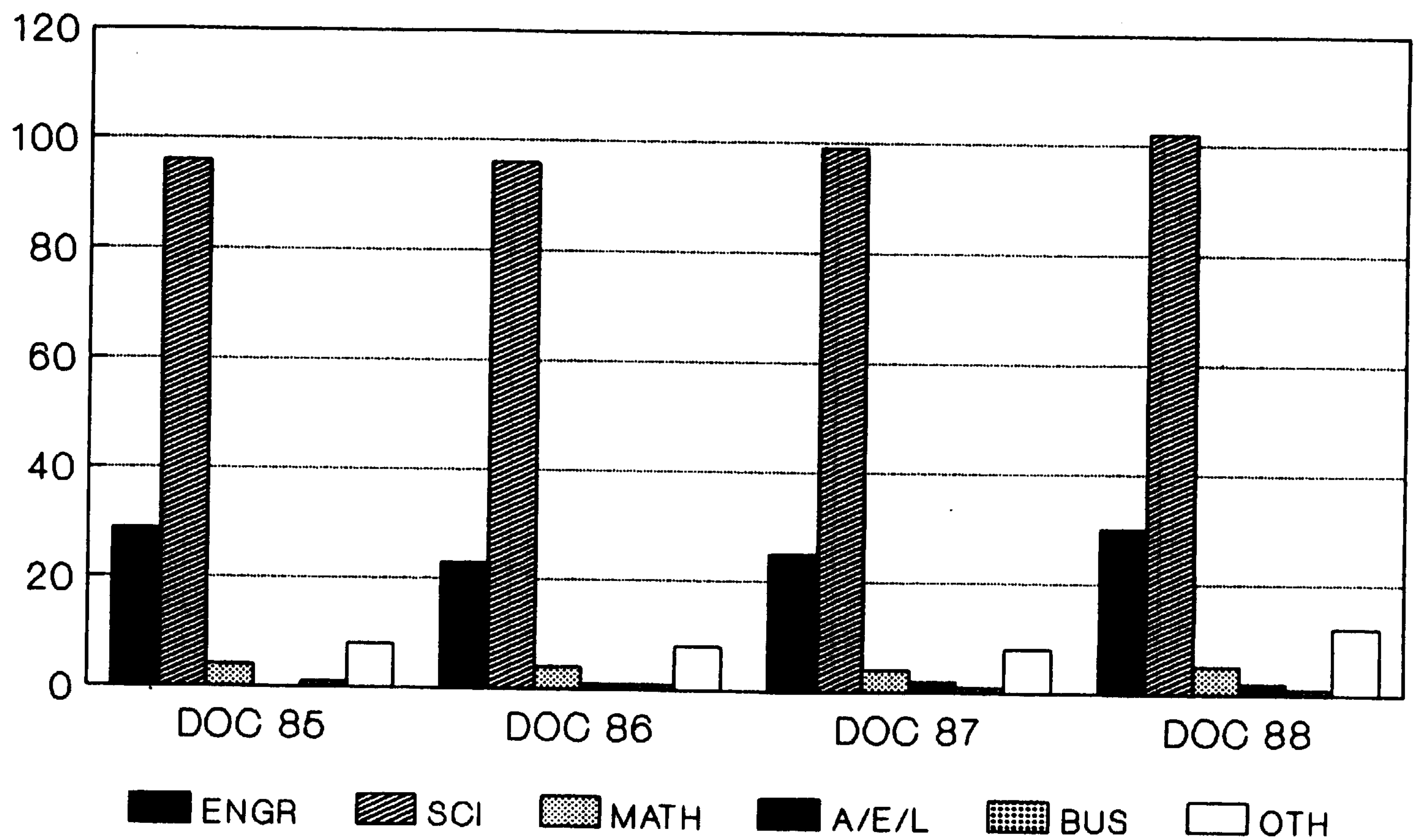

CHART 12 (C)

CHAPTER VIII

RECOMMENDATIONS AND CONCLUSIONS

1.0 INTRODUCTION - ASSUMPTION AND GOALS

2.0 RECOMMENDATIONS FOR NASA AND NSTS

3.0 RECOMMENDATIONS FOR CONTINUED RESEARCH

VIII. RECOMMENDATIONS AND CONCLUSIONS

1.0 INTRODUCTION - ASSUMPTIONS AND GOALS

1.1 ASSUMPTIONS

The following assumptions and opinions are built into the rest of this chapter and are stated here for completeness and in aid of following the rationale of the arguments presented.

The Year of 1988 Was a Stabilizing Year for the Program: This year saw the resumption of flight and a return to business for the program. The pressures imposed by the different investigatory bodies caused by the Challenger accident seems to be abating. Perhaps NASA is just getting used to dealing with the imposed restrictions. While there is still some discontent evident with the public, for the most part, it seems as if the public is relieved that flight has resumed.

There is Still no Integrated, Coordinated Plan for Transition: If such a plan exists, it has not been communicated down through the agency. There is no participative system evident towards developing such a plan.

The Shuttle and Shuttle Program are Still in a Developmental State: There is a large amount of change evident in the

hardware, in the process of readying the shuttle for flight, in the business of determining manifests and in other factors related to delivering the final product of space flight. As a specific example, the control systems are maturing, changing, and developing. As a result of this, the program is not yet at a state where transformation to a truly operational era could occur.

<u>There is Still Some Degree of Confusion About the Strategic Goals of the Shuttle Program:</u> It is not clear that NASA has looked beyond the resumption of flight. If there are clear goals, they are not well communicated.

<u>There Has Been Some Change in the JSC Demographics but they are Still in Poor Shape to Manage an Operational Era:</u> Further explanation of this assumption lies in the demographics section of this report. On the other hand, the demographics have shown some change and are in good shape to plan and begin to manage a transition.

<u>To Some Degree, NASA in General and NSTS in Particular Seems to Have Lost Their Sense of Purpose:</u> While everyone seemed to be committed to getting back to flight, this seems to be the totality of the depth of the commitment. There does not seem to be a sense of getting on with a mission with a purpose or a well stated and understood direction.

The Methods of Management are Changing: A specific example of this is the growth in the interest and use of statistics in managerial decision making.

1.2 GOALS

The following goals are in essence the same as was reported in last years report. In order for NSTS to transition, the following goals are essential:

- o NSTS MUST BEGIN INTEGRATED AND LONG RANGE PLANNING FOR TRANSITION. THIS INCLUDES THE ESTABLISHMENT AND COMMUNICATION OF STRATEGIC GOALS.
- o NSTS MUST SEEK NEW METHODS OF DOING BUSINESS AND ACCOMPLISHING THE STRATEGIC GOALS FOR THE OPERATIONAL ERA.
- o NASA IN GENERAL AND NSTS IN PARTICULAR MUST FIND WAYS OF INFUSING NEW SKILLS, TALENT, AND LEADERSHIP THROUGHOUT THE ORGANIZATION.

These goals are interrelated. Without a plan, a smooth transition will not occur. Without communication of the plan to the work force, unified support of the plan is not possible. Once strategic goals are established, then new methods, in the sense of different from the old or usual ones, must be found to accomplish these goals. Since an operational era will be a new one for NASA, new skills and talent will be required. Since the work force is getting

older, new innovative leadership will be required.

1.3 INTRODUCTORY COMMENTS

The rest of this chapter is devoted to specific recommendations and their related reasons. Strategic issues require a long lead time. There is no more complex example of a technological system extant today than the shuttle program. The size, cost, national importance, and visibility of the program also increase the complexity and therefore the time required to make strategic change. If the shuttle is to transition, then the process must be begun. The recommendations presented are aimed at beginning this process.

It is the firm belief of this research team that NASA must solve its own problems. The only value of an outside influence such as this team is that of stimulating the thought process. It is in this light that the recommendations are presented. The recommendations are presented in two sections, one for NASA and NSTS and the other for continued research.

2.0 RECOMMENDATIONS FOR NASA AND NSTS

2.1 EDUCATE NASA ON THE DIFFERENCES BETWEEN R/D AND OPERATIONS

There seems to be very little knowledge in existence at NASA about what constitutes a truly operational environment.

Since this is a new type of program for the organization there is no reason why this knowledge should exist. For a product as complex as the shuttle, perhaps such knowledge does not exist anywhere. However, for the flight rate to grow, the organization must have some idea of what is required in its operational future state. Without this understanding, it will impossible to plan a path to get there or even to determine if operations is where the shuttle program needs to be.

2.2 DESIGN FOR PRODUCTION AND QUALITY

While programs and structures are changing, now is the time to build in from the bottom up quality and production considerations. Standardization, the shortening of production lines, the stream lining of process flow, and cross training are just a few of the production issues that need addressing.

2.3 DETERMINE THE STRATEGIC AND TACTICAL GOALS AND OBJECTIVES FOR NSTS

Without a plan or some idea of direction, the program will suffer. A task force at the highest level needs to be formed to determine exactly what NSTS is all about and where it should head.

2.4 DEVISE A PLAN TO PROVIDE FOR NEW SKILLS AND LEADERSHIP IN THE ORGANIZATION

As is obvious, this plan must be linked to the plan mentioned earlier. A hard and in depth look at that plan is required to determine the skills and talents necessary to move NSTS towards operations and to keep it there once it arrives. Once the skill mix is determined, a plan along with the related time table is required in order to insure a smooth transition.

2.5 EVALUATE AND INITIATE OPERATIONAL STRATEGIES

The first step is to evaluate the feasibility of an operational arm to manage the shuttle program in light of goals and objectives yet to be established. Then a transition to this state must planned if indeed it is to be achieved.

2.6 RESEARCH INTO SPACE OPERATIONS ENGINEERING SHOULD BE INITIATED BY NASA

It is incredibly naive to believe that the existing knowledge on operations engineering will fulfill the needs of the shuttle program as the flight rate is increased. The space station and future missions under consideration such as a moon base or a Mars mission will require even more knowledge in this area. As a specific example, the logistical considerations alone will require an extension and adaptation of the existing state of the art. Scheduling is

another example of a place where theory will have to be developed. Other examples are numerous. Yet, there is very little concern over the lack of effort to expand, coordinate, or organize knowledge in these operational areas. The situation is very similar to the problems facing the Allies with the invasion of Europe in WW II. Those problems led to the development of a whole new field, that of operations research. The magnitude of the operational issues facing NASA with the programs under consideration surely is at least of an equal magnitude.

2.7 AFTER WORD

If the reader is familiar with the work of this team in the years that have gone before, then much of this chapter, including this after word, will look familiar. This is a telling comment on the year 1988 in the shuttle program. There has been a tremendous amount of work this year with NSTS but little of the work seems to have been directed towards moving the program forward. The major question is whether the shuttle will mature to a point where it decides to plan a transition or whether it will just continue to wander along.

3.0 RECOMMENDATIONS FOR CONTINUED RESEARCH

These recommendations are specific items for this research team or a similar organization dedicated to the

preliminary work required to provide information and guidance in the early stages of transition planning for NSTS.

3.1 THE THEORY OF TRANSITION MANAGEMENT NEEDS TO CONTINUE TO BE ENLARGED, REFINED, AND ADAPTED FOR THE SHUTTLE PROGRAM NEEDS

Specifically, more industrial interviews with companies that have undergone a major transition need to occur. In addition, theory needs to continue to be developed and refined. This includes the development and presentation of research papers on the subject. All of this information needs to be adapted to the structure, style, and need of the shuttle program.

3.2 ANALYTICAL TOOLS OF USE TO THE SHUTTLE PROGRAM NEED TO CONTINUE TO BE DEVELOPED AND PRESENTED

The work on presenting information on statistical decision making needs to be continued and perhaps broadened to a larger audience. Some group needs to continue to serve as a resource in this area to management. Analytical tools to assist with items such as a the determination of a reasonable and realistic flight rate need to continue to be developed. The work on scheduling needs to be continued. The work on scheduling needs to be more closely modeled to fit the shuttle program.

3.3 OPERATIONAL ISSUES AND INDUSTRIAL ENGINEERING TOOLS NEED TO CONTINUE TO RECEIVE EXPOSURE

This includes the day to day interaction of the principal investigator with management as well as the demographic modeling which has been presented.

3.4 THE RESEARCH TEAM NEEDS TO FIND A WAY TO RECEIVE EXPOSURE IN THE METHODS WHICH ARE USED BY OTHER NATIONS TO PROCESS SPACE FLIGHTS

In order to continue to find insight into new methods, it is necessary to understand what is available in other areas. Without new insight, it is more difficult to determine new solutions.